DOCUMENT RESUME

ED 176 367 EA 012 063

TITLE Application of Computer Assisted Energy Analysis Seminar (Pittsburgh, Pennsylvania, April 12-14, 1977).

INSTITUTION Association of Physical Plant Administrators of Universities and Colleges, Washington, D.C.

PUB DATE Apr 77

NOTE 253p.; Parts of Section VI may not reproduce clearly

EDRS PRICE MF01/PC11 Plus Postage.

DESCRIPTORS Administrative Personnel; Air Conditioning; *Building Operation; *Computer Programs; Consultants; Cost Effectiveness; Data Collection; Electrical Systems; *Energy Conservation; *Facility Requirements; Heating; Higher Education; *Life Cycle Costing; Simulation; *Systems Analysis; Utilities

ABSTRACT

The intent of this seminar presentation was to demonstrate that with proper care in selecting and managing energy analysis programs, or in choosing commercial services to accomplish the same purposes, universities and colleges may derive significant benefits from efficient and economical use and management of their facilities. The workbook begins with an overview of energy analysis followed by a description of the types of computer programs available and various levels of analysis. The concept of time value of money is explained and steps for calculating a life-cycle cost analysis are given. Interpretation and application of the results of a computer energy analysis provide examples of daily solar loads revealed by the computer program and some of the control strategy possible. The staff and training requirements and procurement and management of a computer program are discussed. A directory of energy consumption analysis programs and a summary of one consultant's computer programs and presentation graphics are included. Two case studies describing the application of computer assisted energy analysis illustrate both the process and results that may be obtained. (Author/MLF)

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Application of Computer Assisted Energy Analysis Seminar

April 12 - 14, 1977

Pittsburgh Hilton Hotel

Pittsburgh, Pennsylvania

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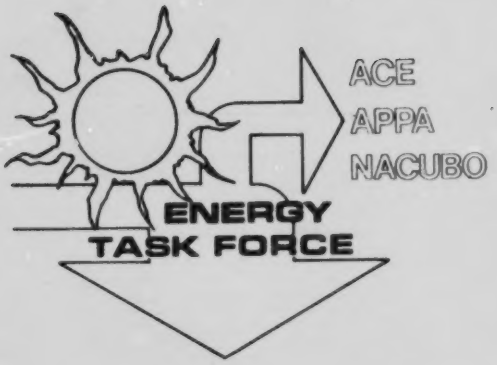

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APPLICATIONS OF COMPUTER ASSISTED ENERGY ANALYSIS SEMINAR

THE ASSOCIATION OF PHYSICAL PLANT ADMINISTRATORS OF UNIVERSITIES AND COLLEGES

PITTSBURGH HILTON HOTEL - PITTSBURGH, PENNSYLVANIA

BALLROOM NUMBER 3

APRIL 12-14, 1977

TUESDAY, APRIL 12, 1977		SPEAKER
9:00 AM - 5:00 PM	Registration	
1:00 PM - 1:10 PM	Welcome	
1:10 PM - 2:00 PM	An Overview: "What Is An Energy Analysis; How Do Computers Fit In?"	Jones
2:10 PM - 3:15 PM	Types of Programs Available and Various Levels of Analysis	Jones
3:15 PM - 3:30 PM	Refreshment Break	
3:30 PM - 4:30 PM	Energy Economics and Life Cycle Costing Analysis	Anderson
4:40 PM - 5:30 PM	Interpretation and Application of Results	Jones
5:40 PM - 6:45 PM	Social Hour	
6:45 PM	Dinner (Open)	

WEDNESDAY, APRIL 13, 1977		
8:00 AM - 12:00 PM	Registration	
8:30 AM - 10:30 AM	Implementing the Program — In House: Staff Requirements and Training Time and Cost	Anderson
10:30 AM - 10:45 AM	Refreshment Break	
10:45 AM - 12:00 PM	User Experience/Information Exchange	Jones, Anderson, Duddly, Meriwether
12:00 PM - 1:00 PM	Group Luncheon	
1:00 PM - 3:00 PM	Utilization of Consultants and Outside Computer Services - Ross Meriwether	Meriwether
3:00 PM - 3:15 PM	Refreshment Break	
3:15 PM - 5:00 PM	Summary: "What Can A User Really Learn From Computerized Energy Analysis?"	Jones
5:00 PM - 6:30 PM	Boat Trip	

THURSDAY, APRIL 14, 1977

8:30 AM - 11:30 AM - Group Participation in a Program Operation Demonstration under Simulated Situations - "The Trane Company/ Trace Program"	Moderator- Jones Speaker - Duddly
11:30 AM - 12:00 PM - Certificate Presentations	Jones

APPLICATIONS OF COMPUTER ASSISTED ENERGY ANALYSIS SEMINAR

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INSTRUCTIONS: Use this sheet to write down questions that will be answered during the Experience Exchange Session on Wednesday, April 13 at 10:45 A.M.

QUESTION:

NAME: _____

INSTITUTION: _____

QUESTION:

NAME: _____

INSTITUTION: _____

QUESTION:

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Application of Computer Assisted
Energy Analysis Seminar
Pittsburgh Hilton
Pittsburgh, Pennsylvania
April 12-14, 1977

SEMINAR EVALUATION

We hope that you have found this seminar to be stimulating and that you have come away with some fresh ideas. The Association Workshop Committee will meet to evaluate the sessions offered as a guide for future planning. Your input is essential to a meaningful review. Please fill out this form and return to APPA staff at the Certificate Presentations Session, April 14, 1977 at 11:30 A.M.

The length of the program was: too long___ about right___ too short___

The pace of the program was: too fast___ about right___ too slow___

Please rank each item below from 1 through 4. (a "1" being the highest, a "4" being the lowest.)

	1	2	3	4
1. I found the Seminar as a whole...	____	____	____	____
2. In relation to my responsibilities in the institution or system I found the relevance of the Seminar...	____	____	____	____
3. Rate the following characteristics of the Workshop:				
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b. Overall quality of the faculty	____	____	____	____
c. Program scheduling	____	____	____	____
d. Group participation	____	____	____	____
e. Facilities	____	____	____	____
f. Materials	____	____	____	____
4. Would Seminars similar to these be useful for your staff members (i.e., supervisors, managers, etc.)?	____	____	____	____

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___ more than 15,000

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Please rank each Seminar session you attended from 1 through 4 in terms of content and instruction. (a "1" being the highest, a "4" being the lowest.)

	Content				Instruction			
	1	2	3	4	1	2	3	4
An Overview	___	___	___	___	___	___	___	___
Types of Programs	___	___	___	___	___	___	___	___
Energy Economics	___	___	___	___	___	___	___	___
Interpretation	___	___	___	___	___	___	___	___
Implementation - In House	___	___	___	___	___	___	___	___
Utilization of Consultants	___	___	___	___	___	___	___	___
A Summary	___	___	___	___	___	___	___	___
Trane Demonstration	___	___	___	___	___	___	___	___

Additional Remarks and Comments:

PREFACE

The authors of the following workbook wish to thank R.W. Anderson and the Seminar Advisory Committee for their guidance in establishing the theme and overall outline of this Seminar and Mr. Anderson and the APPA Staff for their efforts in arranging for the many activities associated with the program.

The authors, however, take full responsibility for the materials in the workbook and in the verbal presentations. The specific responsibility is as follows:

Sections 1, 2, 4, 7 and the first case study in the appendix were prepared by Dr. Jerold W. Jones of the University of Texas at Austin.

Sections 3 and 5 were prepared by Dr. Swiki A. Anderson and Dr. T.R. Lalk of Texas A & M University and Dr. Anderson prepared the second case study in the appendix.

Section 6 materials were prepared by Mr. Ross Meriwether of San Antonio, Texas and Section 8 materials were prepared by the TRANE Company of LaCrosse, Wisconsin.

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SECTION I

OVERVIEW OF ENERGY ANALYSIS

OUTLINE

Introduction

Energy Audits
- Building Description
- HVAC System Description
- Operating Schedules
- Utility Consumption

Direct Energy Use

Evaluation of Conservation Opportunities
- Primary Equipment
- HVAC Systems
- Building Heat Gain/Loss

OVERVIEW OF ENERGY ANALYSIS

Utility rates have increased to the point that the cost of energy is now a significant part of owning and operating expenditures. This has created a situation where it is as necessary to monitor energy consumption as to maintain adequate financial records. With energy, the consumer has little or no means of controlling unit cost; the price of a kwh of electricity or mcf of gas is usually not negotiable. The only control possible is on the rate of consumption of kwh or mcf. To establish adequate control, it is necessary to set procedures for energy accounting which are considerably more detailed than those used in the past. It is becoming increasingly important to itemize energy expenditures by end use rather than simply as single entry items for each fuel or energy source.

The first step toward identifying and eliminating waste, and the only way to exercise responsible management control of energy use, is the careful analysis of the energy requirements of our facilities.

For the purposes of the following presentation, we shall define energy analysis as the systematic application of engineering and economic principles to the evaluation of energy use in buildings. Analysis procedures will focus on answering two questions:

1) How much energy is required to maintain comfort and supply the utility needs of a building?

2) How can these energy needs be met most efficiently and economically?

The objective of the analysis is also to identify those means of minimizing energy requirements and maximizing system and equipment efficiencies which will not reduce the level of service provided. The primary tools which will be used are:

1) Energy audits

2) Modeling and simulation procedures

Each plays an important role and each is facilitated by the use of high speed digital computers.

The steps of a building energy analysis might be briefly outlined as follows:

1) Evaluation of present energy use patterns
   a) Direct use (lighting, equipment, etc.)
   b) HVAC system use (fans, pumps, chillers, etc.)
2) Definition of building energy needs
   a) Comfort control (heating/cooling loads)
   b) Utility services (lighting, domestic hot water, etc.)
3) Description of HVAC system
   a) Terminal delivery system (fans, coils, etc.)
   b) Control operation and schedules
   c) Heating/cooling delivery system (chill water pumps, etc.)
4) Description of HVAC equipment
   a) Chillers, boilers and associated equipment
   b) Control and operating schedules
5) Economic evaluation
   a) Life cycle and first cost analysis

The emphasis placed on each of these items depends on the particular application. For example, the evaluation of present consumption would be omitted in analyzing a new building design. Conversely there may be less focus on the second step in existing buildings where the building configuration and physical characteristics are already established. In new building design, the load analysis might be performed for a number of options while in an existing building, the calculations may be done only once. The relative importance of each step will be discussed in the following sections.

Energy Audits:

Any energy management effort should begin with an evaluation of present patterns of energy consumption. In all too many cases attention has been focused on conservation options which offer little potential for saving energy, while other areas where significant savings can be effected are overlooked. This situation can be avoided by beginning a project with an "energy audit". An energy audit is similar to a financial audit except it examines the flow, investment, and benefit derived from energy resources rather than financial resources. In both cases, the key to success is a carefully established procedure and maintenance of thorough records. Although audit procedures should be tailored to a specific application, a few basic steps can be outlined which will have broad application.

The information which should be obtained for, or developed during, the energy audit process may be summarized as follows:

1. Building Description
   a) Physical characteristics
   b) Heating and cooling load estimates
2. HVAC System Description
   a) Air/water distribution system performance and component energy requirements
   b) Primary equipment operating characteristics (including part load performance, if possible)
3. Operating Schedules
   a) Occupancy
   b) Ventilation
   c) HVAC system
4. Historical Operational and Consumption Data

Working from this data base, it is possible to quantify the various components of end use energy consumption in a building. Where this has been accomplished it is then possible to identify areas where conservation efforts will be most effective and economically feasible.

The first step in the audit procedure is to gather all the information available. In some instances the building plans, specifications, supporting documentation and daily energy consumption records may be available. In other cases, only the monthly utility bills will be available. Whatever the case, the data should be collected and organized so as to be readily accessible for the remainder of the audit. The more detailed the information, the more complete the audit. The type of building information which will be useful in the audit is shown in Figure 1-1.

Utility consumption - electric, natural gas, oil, etc. should be obtained. Annual consumption should be converted to a common unit, summed and broken down on a per square foot basis as illustrated by Figure 1-2. This will give rough indication of the relative efficiency of the building. For exampls, an office or classroom building operating 10 to 12 hours per day, 5 days per week witn an annual consumption below 70,000 Btu/ft^2/year is relatively economical while one requiring 300,000 Btu/ft^2/year is a prime candidate for conservation projects. Utility data should also be tabulated or plotted in the form of monthly sums to indicate seasonal trends. If possible, data should be plotted on a daily basis for selected weeks during heating, cooling and an intermediate season periods. If daily data is not available, it would be worthwhile to explore the possibility of obtaining it for even a short period. This may require having someone read the available meters daily for several weeks. However, it would at least identify differing levels of consumption between week days and weekends and indicate what portion of the energy use is related to occupancy and lighting schedules.

In the case of buildings, energy use can be divided into two fundamental categories:

1. Direct use for lighting, vertical trnasportation, office and/or special equipment, etc.

2. Use for maintaining comfortable conditions within building.

Figure 1-1

Line No. (Circle Appropriate Items and Fill in Blank)

1. Primary Bldg. Use:
2. Length, Feet and Orientation _____ Ft. N W S E
3. Width, Feet and Orientation _____ Ft. N W S E
4. Number of floors:
5. Floor area, gross sq. ft.: Lines 2 x 3 x 4 = _____ sq. ft.
6. Window Glazing: single, double, clear, reflective, absorbing
7. Window Type: fixes sash, double hung, casement
8. Window Condition: Loose fitting, medium, tight
9. Windows: Number area, Orientation

   Orientation: _____ No.: _____ Area: _____
10. Windows: Number area, Orientation

    Orientation: _____ No.: _____ Area: _____
11. Windows: Number area, Orientation

    Orientation: _____ No.: _____ Area: _____
12. Windows: Number area, Orientation

    Orientation: _____ No.: _____ Area: _____
13. Door types and numbers:

    1 - single; *2 - vestibule; *3 - revolving

    Orientation: _____ No.: _____ Type: _____ Area: _____
14. Door Types:

    Orientation: _____ No.: _____ Type: _____ Area: _____
15. Door Types:

    Orientation: _____ No.: _____ Type: _____ Area: _____
16. Door Types:

    Orientation: _____ No.: _____ Type: _____ Area: _____

Figure 1-1 (cont'd)

Line No.

17. Walls: Net Area, Orientation

Orientation	Gross Area	Net Area*	"U" Value
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

*net area = gross area - window

18. 1) Number of working hours/wk. _____

2) Number of occupants _____

(a) For offices, employees & visitors; stores, employees & customers; religious buildings, occupants

19. Number of custodial hours per week _____; After normal working hours _____.

20. Temperature and relative humidity inside conditions:

Season	Temperature	Relative Humidity
a. Winter	Occupied Hours ___ °F	_____ % RH
b.	Unoccupied Hours ___ °F	_____ % RH
c. Summer	Occupied Hours ___ °F	_____ % RH
	Unoccupied Hours ___ °F	_____ % RH

21. Ventilation: Outside air:

a. During occupied hours on/off, amount in total CFM _____

b. CFM/person: Line 21a ÷ Line 18b = _____

Source of Information:

1 - 17 Building plans and specifications

"U" values from standard tables

18 - 21 Building manager or operating personnel

Figure 1-2 Annual Fuel and Energy Consumption

Type*	Conversion Factor	Annual		Jan.		Feb.		Mar.		Nov.		Dec.	
		Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)

Floor area _____

Btu/ft^2/year _____

Type	Oil (gallons)	Natural Gas (cuft)	Electricity (KwH)	Steam (10^3 lb)	Other (units)
Conversion Factor	(#2) 138 (#6) 146	1.0	3.413	900	

ource of Information:

nthly utility bills

In a typical office building, 30% to 40% of the energy consumption is attributable to direct applications (primarily lighting and office equipment) while the remaining 60% to 70% is utilized by the HVAC system. The distribution would be similar for classroom buildings. Evaluation of the direct energy consumption is generally straightforward. Determining the energy requirements of HVAC system components requires a more complex analysis. Table 1-1 illustrates the energy monthly use distribution for a 12 story, 260,000 square foot office structure in Austin, Texas, determined through the energy audit procedure. These results may be more detailed than would be required in some situations. However, as the intent of the audit is to evaluate the energy use efficiency of the building, all available information should be utilized to provide as complete a picture as possible.

Direct Energy Use

Lighting is the largest element of the direct use category. In evaluating the energy used by lighting, it is necessary to determine both the installed lighting capacity in KW and to evaluate the lighting use patterns. If building plans and specifications are available, they will indicate the number, type, and wattage of installed fixtures. However, it is necessary to check to determine if actual installations match the design. In some cases, substitutions may have been made during construction or in the process of remodeling. Even though it is necessary to check the actual installation, it simplifies matters if the plans are available as a starting point. If plans are not available, a rough sketch of each floor should be made and a survey conducted to determine the installed lighting and equipment in each area, noting the installed KW for each space on the sketch. It must also be noted that fluorescent fixtures require more power than indicated by the rating printed on each bulb. This is due to the ballast required to provide the appropriate current flow

Table 1-1

TOTAL ANNUAL CONSUMPTION

		10^9Btu/year
Electricity:	11,500,000 KwH	39.4
Natural Gas:	26,302 MCF	26.3
TOTAL		65.7
Thousand Btu/ft^2/year	252	

DISTRIBUTION:

ELECTRIC ENERGY:	Winter	Summer
Direct Use		
Lights	26%	23%
Office Equipment	10%	8%
Elevators	1%	1%
Miscellaneous	1%	1%
Total Direct Use	38%	33%
HVAC Use		
Chillers	17%	27%
Cooling Auxiliaries	9%	8%
Cooling Tower Fans	3%	4%
Heating Auxiliaries	4%	3%
Air Handling Units	23%	20%
Outside Air Handlers	1%	1%
Exhaust Fans	5%	4%
Total HVAC Use	62%	67%

NATURAL GAS ENERGY:	Winter	Summer
Direct Use	4%	6%
HVAC Use		
Boilers	96%	94%

for bulb operation. The additional power requirement for the ballast is approximately 20% and must be included in the figures. Figure 1-3 indicates a type of survey form useful in evaluating lighting energy requirements. Figure 1-4 provides a similar format for office and miscellaneous equipment.

As computer installations are more and more frequently found in buildings, they also must be considered as part of an audit. The best source for information on power requirements for these items are the equipment suppliers. With this data and operating schedules electric consumption may be estimated. Vertical transportation usually does not represent a significant percentage of building energy use but should be checked. Figure 1-5 indicates the kind of information which is pertinent for this item.

HVAC Energy Use

At this point, one is faced with a decision as to the level of analysis which is warranted, or possible, relative to the heating and air conditioning system in the building. As the HVAC energy consumption is the largest component of energy use and represents a significant opportunity for conservation, one is inclined to want to conduct a complete analysis. However, HVAC system operation is rather complex and a detailed analysis may not be justified. The following possible options should be examined:

1. A cursory analysis that simply attributes the difference between the gross energy consumption and the direct energy uses determined by the building survey to the HVAC system, attempting only to divide this between air distribution,heating and cooling functions.
2. Carry out an analysis which estimates the variation in energy consumption with
   a) climatic data
   b) system characteristics
   c) internal loads

Figure 1-3

LIGHTING

1. Electric lighting system in primary spaces such as office areas, halls of worship, store sales areas.

   (1) Incandescent; (2) Fluorescent; (3) Other note _____; (4) # of fluorescent fixtures _____; (5) # of lamps per fixture _____; (6) Wattage per lamp _____; (7) Total wattage of all fluorescent fixtures _____; (8) Total wattage of all incandescent lamps _____; (9) Total wattage of incandescent and fluorescent lamps _____. (10) Hours operation/week _____

2. Lighting fixtures in secondary spaces, such as corridors, toilet rooms, storage rooms.

   (1) Incandescent; (2) Fluorescent; (3) Other note _____; (4) # of fluorescent fixtures _____; (5) # of lamps per fixture _____; (6) Wattage per lamp _____; (7) Total wattage of all fluorescent fixtures _____; (8) Total wattage of all incandescent lamps _____; (9) Total wattage of incandescent and fluorescent lamps _____. (10) Hours operation/week _____

3. Total installed wattage: Lines 1 (9) + 2 (9) = _____.

4. Average installed watts/sq. ft. _____.

5. Total wattage of exterior lighting for: (1) Security _____ (2) Parking lots and drive _____. (3) Hours operation/week _____

6. Area of parking lots _____ length x _____ width = _____ sq. ft.

7. Parking lot lighting in watts/sq. ft. _____ w/sq. ft.

Source of Information:

Building plans and/or survey of building

Figure 1-4

OFFICE EQUIPMENT

1. Typewriters No. _____ Watts _____ Hours of use _____

   " No. _____ Watts _____ Hours of use _____

   " No. _____ Watts _____ Hours of use _____

2. Duplicating Equipment _____ No. _____ Watts _____ Hours of use _____

   " _____ No. _____ Watts _____ Hours of use _____

   " _____ No. _____ Watts _____ Hours of use _____

3. Coffee Makers No. _____ Watts _____ Hours of use _____

4. Miscellaneous Equipment

   Type _____ No. _____ Watts _____ Hours of use _____

   Type _____ No. _____ Watts _____ Hours of use _____

   Type _____ No. _____ Watts _____ Hours of use _____

Source of Information:

Survey of building or estimates

Figure 1-5

VERTICAL TRANSPORTATION

1. Escalators: Number _____ Operation hours/day _____

2. Elevators: Number _____ *Type: Gear, Gearless, Hydraulic Operation

   Hours/day _____ *Total connected H.P. _____.

Source of Information:

Building plans and specifications

d) equipment performance

e) building characteristics

An analysis which considers these factors will provide a second order of energy use information and a more realistic basis for identifying and evaluating conservation opportunities. It is at this point that modeling and simulation procedures enter the picture. Their introduction into the analysis may also require the use of computers. It is possible to complete an analysis at this level without them, but if a large number of buildings are to be examined, computer analysis may be the most economical approach. It is also at this point physical plant directors may begin to consider obtaining outside assistance, a point we will discuss in detail later.

3. Develop a complete annual load calculation and system simulation. This level of analysis requires utilizing one of a number of computerized analysis procedures now available. Again, outside assistance may well be required, for reasons of both available personnel time and experience. For the computer studies, the type and amount of input data required will depend entirely on the particular program being used. Computer based analysis provides several levels of output information ranging from annual summaries to hourly detail, if desired.

When the computer analysis is used in the audit procedure, the next step - evaluation of conservation options - should be undertaken at the same time. The conservation option analysis is a natural extention of the computerized audit and generally will require little more input information.

The relative costs of level 1, 2 and 3 analysis will be discussed in a later section. Costs will depend more on the requirement for additional personnel or outside consulting assistance rather than on computer charges. For level 2 and level 3 analysis the major effort, and thus the cost, is associated with collecting and interpreting data. The cost of the actual computer use will, in general, not be a major

factor. Thus, a level 3 analysis may not automatically be more expensive than a level 2 analysis. A more complete description of the requirements for each of these levels of analysis will be presented in Section 2.

Figures 1-6 through 1-8 indicate the type of HVAC system and equipment data which should be obtained as input to any of three levels of analysis. Additional information may also be required for levels 2 and 3.

Referring again to Table 1-1 which summarizes results from an energy audit, one can pick out target areas for conservation projects.

1) reduce internal loads
2) reduce ventilation loads
3) modify the distribution system to reduce energy consumption
4) improve the efficiency of the chillers

That these items are targets for conservation efforts is certainly no surprise. However, with the data available from the audit procedure, it is possible to quantify the impact conservation programs will have and thus justify them. Also the minimal impact of transmission through the building envelop as indicated by the data of Table 1-2 may well be a surprise. Recognizing this - and being able to quantify this result - may save a sizeable expenditure for architectural changes in the building which may have been undertaken otherwise.

Evaluation of Conservation Opportunities

The modeling and simulation techniques used in evaluating conservation options are essentially the same as those used in the energy audit analysis at level 2 or 3. The only difference being the number of system and control options simulated. The same input data is utilized except for that modified to describe the specific changes being considered. Therefore, the audit process should be considered as the first phase of the evaluation.

Figure 1-6

PRIMARY EQUIPMENT

A. Heating

1. Boilers or furnace type for space heating (Circle items)

(1) Hot water; (2) Low pressure steam; (3) High pressure steam; (4) Fire tube; (5) Water tube; (6) Cast iron; (7) Steel; (8) Gravity hot air; (9) Forced warm air.

2. a) Boiler or furnace rating _____ BTU x 10^3/hr. or

_____ Boiler H.P. Number of units _____.

b) Peak load combustion efficiency _____%.

B. Cooling

1. Compressors and chillers:

(1) Number _____

(2) Rating of each in tons of refrigeration _____

(3) Total tons of refrigeration (1) x (2) = _____

(4) If electric drive, total motor horsepower _____ H.P.

(5) If absorption units, total peak steam consumption _____ H.P.

2. If central air conditioning systems, indicate: (1) Cooling tower motor sizes total _____ H.P.; (2) Air cooled condenser motor sizes total _____ H.P. Condenser pumps No. _____

Total _____ H.P.

3. If room air conditioners or through-the-wall units: Indicate

(1) total number _____ (2) Horsepower _____/unit

(3) Total connected Horsepower (1) x (2) = _____.

Source of Information:

Equipment, specifications and/or building survey

Figure 1-7

HVAC SYSTEMS

Check the systems and fill in appropriate information:

1. All air HVAC systems: fill in blanks

   (1) system type* _____ a) Number of air handling units _____

   b) Total Horsepower _____

   c) Total CFM/air handling unit _____

   d) Static pressure _____

   e) Reheat: Yes ___ No ___

   Type reheat coil: 1. hot water; 2. steam; 3. electric

   f) House of operation/week _____

2. Water-air systems:

   (1) system type* _____ a) Number of units _____

   b) Total connected horsepower _____

*If more than one system type, repeat data for each type in building.

3. Pumps

   (1) Chilled water pumps a) Number of units _____

   b) Total connected horsepower _____

   Hours of operation _____

   (2) Condenser water pumps a) Number of units _____

   b) Total connected horsepower _____

   Hours of operation _____

   (3) Boiler feed pumps a) Number of units _____

   b) Total connected horsepower _____

   Hours of operation _____

   (4) Hot water pumps for space heating a) Number of units _____

   b) Total connected horsepower _____

   Hours of operation _____

Figure 1-7 (cont'd)

(5) Recirculating pumps for domestic hot water a) Number of units _____

b) Total connected horsepower _____

Hours of operation _____

4. Fans

(1) Outside air fans a) Number of units _____ CFM/fan unit _____

b) Total connected horsepower _____ Hours of operation _____

(2) Supply air fans

a) Number of _____ type of multivane fans _____ HP _____ CFM/fan unit _____

b) Number of axial fans _____ HP _____ CFM/fan unit _____

c) Number of propeller fans _____ HP _____

5. Check if installed:

(1) Fin tube radiators _____ (5) Supply and return ducts _____

(2) Cast iron radiators _____ (6) Outside air dampers _____

(3) Radiant heating coils _____ (7) Steam piping _____

(4) Hot water piping _____ (8) Exhaust duct work _____

Source of Information:

Building plans and specifications

Figure 1-8 Annual Fuel and Energy Use for Domestic Hot Water

Method of generation and storage: Separate water heater; (1) Oil; (2) Gas; (3) Electric; (4) Coal; (5) Tankless heater on space heating boiler; (6) Tank heater on space heating boiler; (7) Storage tank size if any ____ gals.

Estimated annual usage:

(1) Office Bldgs: Average occupancy x 750 ___ gal/yr.
(2) Restaurants: Meals served/yr. x 3 gal/meal = _____ gal/yr.
(3) Religious Bldgs: Average occupancy x 50 gal/yr. = _____ gal/yr.
(Does not include special cooking facilities)
(4) Stores: Average occupancy x number of days = _____ gal/yr.
(5) For residential buildings - 7200 gal/capita/yr.
(6) For schools - 50 gal/capita/week

Type	Conversion Factor	Annual		Jan.		Feb.		Dec.	
		Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)	Qty.	Btu's (1000's)
1. ___	_____								
2. ___	_____								

Type	Oil (gallons)	Natural Gas (cuft)	Electricity (KwH)	Steam (10^3 lb)	Other (units)
Conversion Factor	(#2) 138 (#6) 146	1.0	3.413	900	

Source of Information:

Estimates of occupancy and item (1) above

Table 1-2

BUILDING HEAT GAIN/LOSS*

Design Day	Summer (10^6 Btu/Day)	Winter (10^6 Btu/Day)
Building Envelope	+17	-43
Ventilation	+19	-10
Internal Heat Gain	+63	+63

Annual	Gain (10^6 Btu)	Loss (10^6 Btu)
Building Envelope	+ 5500	-4300
Ventilation	+ 4100	- 400
Internal Heat Gain	+22,400	-----

*Note: These values are estimates for a particular building in Austin, Texas, They are presented only to illustrate the relative size of each load component. (See Appendix B).

In examining energy conservation options, it is again useful to divide energy consumption between "direct consumption" and "HVAC consumption" items.

In the direct energy category the primary impact can usually be determined easily. For example, consider a building having 1000 two-lamp fluorescent luminaries with 40 watt lamps operating from 7:30 am to 6:30 pm. Figure 1-9 illustrates two possible use patterns, one with the lights operating continuously and the other on an as needed basis. The difference amounts to a 263 kwh per day savings or 5875 kwh per month. This analysis required only information about the installed capacity, operating schedules and an estimate of a percentage of time the lights could be turned off during the work day. A computer analysis certainly is not required. However, there is a secondary consequence of this action that should not be ignored. As internal (lighting and miscellaneous equipment) loads are a major source of the cooling requirement, reducing the lighting use will affect the HVAC system energy consumption. If the space requires cooling, reducing the lighting will certainly reduce the cooling load, but what if heating is required? Then reducing the lighting load will increase the heating load. The question is by how much and what is the balance between cooling savings and heating increases? This interaction is not as easily evaluated. However, with computerized models and system simulation such interactions and "trade offs" can be analyzed. This point serves to illustrate the utility of computerized procedures even for a relatively simple modification.

As noted previously, the evaluation of HVAC system energy requirements is considerable more difficult than that for direct use systems. This complexity carries over into the evaluation of conservation option, particularly when it comes to evaluating the impact of a series of possible activities. In terms of energy savings the total is more likely to be either greater than or less than the sum of the savings of individual actions than it is to be equal to the sum of such savings. It is, of course, possible to

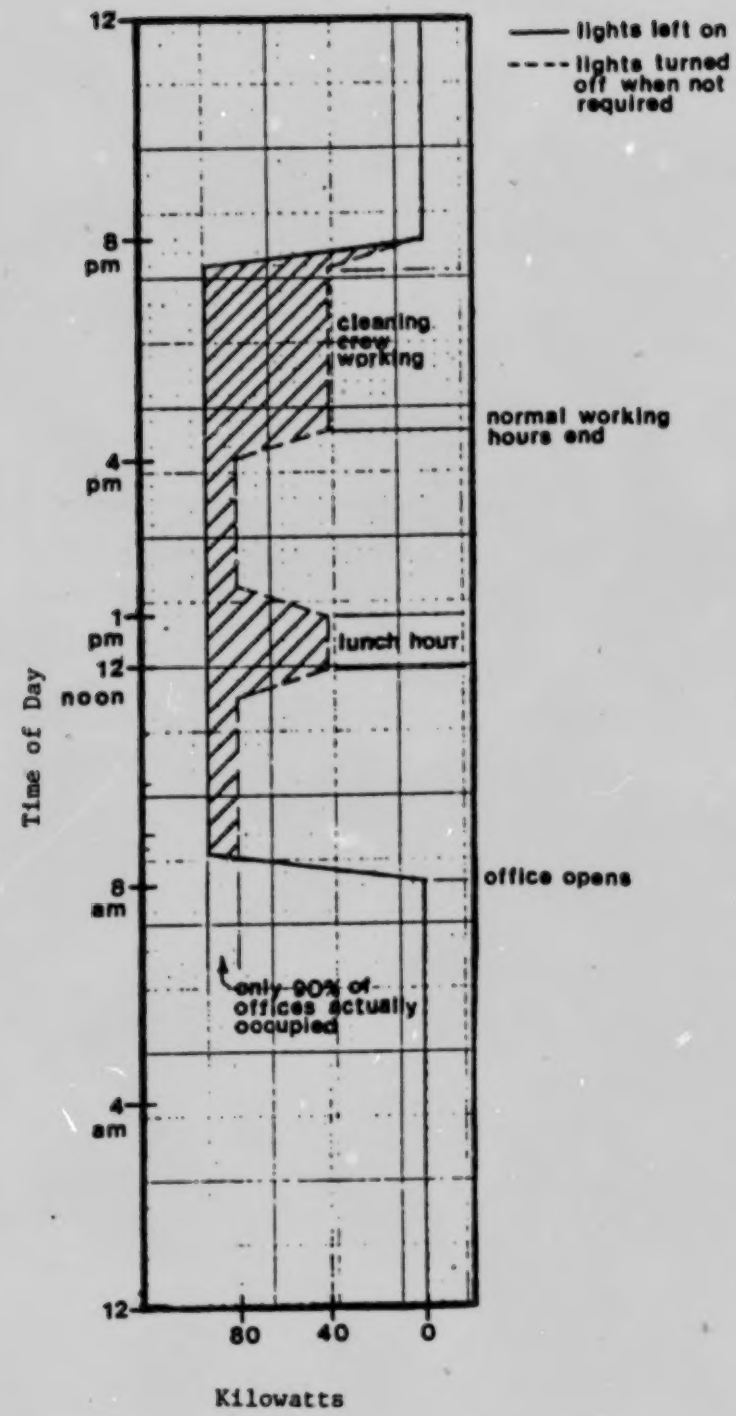


Figure 1-9 Reduction in Power Due to Turning Off Unnecessary Lights

make estimates without employing computer analysis. However, the reliability of estimates of saving is greatly improved by more thorough analysis. Also, once the basic data has been assembled, one can investigate a number of options rapidly with a computerized analysis and for little extra expense. For example, once a system has been described and space loads calculated, it is a relatively simple process to evaluate the effects of varying internal loads, air flow rates, temperature set points or control operation modification, hours of operation, ventilation rates, or replacement of existing equipment with more efficient units. With a computerized analysis, evaluating the one system configuration may be more time consuming than with non-computerized analysis but any additional analysis is much faster. Examples of this type analysis will be presented in sections 4 and 7.

SECTION II

TYPES OF PROGRAMS AVAILABLE AND VARIOUS LEVELS OF ANALYSIS

OUTLINE

Choosing a Computer Program for Energy Analysis
- Basic Elements
- Types of Programs
- Levels of Complexity

Level I - Analysis (Non-Computerized)

Level II - Analysis (Audit and Evaluation Options)

Level III - Analysis (Simulation)

NECAP Program

NBSLD Program

TYPES OF PROGRAMS AVAILABLE
AND VARIOUS LEVELS OF ANALYSIS

Choosing a Computer Program for Energy Analysis:

There is no single "ideal" program which will be best suited for all possible energy analysis applications. The requirements of various tasks may be significantly different. Choosing an appropriate level of analysis may well be the most difficult step in the process. Unfortunately, an inappropriate choice may prove to be expensive, time consuming, and worst of all, misleading. Computer output seems to have a certain "mystique" that often generates a sense of awe in those inexperienced in computer applications. If this creates an impression of "correctness" or "completeness" which does not actually exist, the consequences may be serious. One must assume an attitude of skepticism in examining various programs and choose carefully. Additionally, the user must recognize that the results will rest as heavily on the quality and appropriateness of the input information as on the structure and "accuracy" of the program. Those who work with computer analysis learn that there is truth in the maxim "garbage in - garbage out".

These comments are certainly not intended to discourage computerized energy analysis. They are intended to emphasize the absolute necessity of careful planning and development in instituting an energy analysis program. What may seem "extra" time spent in the early stages will be repayed many times over in later effort.

As noted previously, there are four basic elements in building energy analysis programs:

a) Load Calculations
b) System Simulation
c) Equipment Simulation
d) Economic Analysis

The way each of these is handled in a particular program is influenced by its intended application. For example, the specificity of available input data is quite different for a new building project in the design stages and for an existing building being retrofit for conservation purposes.

In the case of the new building, very little detail may be available, or for that matter required, at the time of the initial analysis. Concern may be centered on loads and on architectural feature, such as geometric configuration, fenistration and building materials. Therefore, a flexible load program with stored tubular data for various wall sections, glass types, and operating schedules would be most useful. Once the building design has been set, then the focus shifts to the system analysis. Again a program with a number of built-in optional systems would be most valuable. Such a program might provide the means of comparing two dozen system and control options with very little input data requirement. It is important to realize that the relative performance is much more important than an absolute accuracy when comparing the impact of many options. You would like to be able to narrow the choice relatively quickly in the early stages and defer optimization until the building and system designs are set. Also the ability to select equipment in a "generic" sense and carry the analysis through an economic analysis is very important. But again a broad brush approach, utilizing stored tabular data, is quite adequate for new building projects.

The type of program required for the evaluation of conservation options in an existing building is very different. In this case the input data is very specific and fixed. You may no longer be in a position of looking for relative measures of performance. Instead you may wish to be able to stimulate the performance of a specific building and system. In this case access to the simulation procedure itself (the algorithm) may be required to make the model fit.

This necessitates an entirely different level of data input. Considering the number of different systems which may exist on a single campus, this accessibility and program flexibility become very important. However, by carefully choosing a program, one may still be able to move quickly through an analysis and avoid "rewritting" the system simulation each time.

There is, however, a word of caution which must be interjected at this point. An analysis is only as "strong" as its "weakest link" and an overall assessment of the available input data and program capability must precede any actual effort to conduct a computerized analysis. Even though some specific data may be available, it may be necessary to be content with evaluating trends and cause and effect relationships in existing buildings. There is little point in trying to closely match measured energy consumption data if you are uncertain about the operating characteristics of system components such as dampers, control settings, or even operating schedules. Fortunately, with the appropriate choice of analysis procedure, identifying general relationships or even order of magnitude effects may be very useful. For example, such information could indicate an option should be neglected or that further detailed study is warranted.

In existing building analysis there is generally not much justification for an extensive evaluation of architectural features. There may be little that can be economically done to modify them. Thus the focus of the analysis, and the criteria for choosing a program, should shift to their systems and equipment analysis capabilities.

At this point it is appropriate to look at the various levels of complexity one should consider in choosing an energy analysis program (including one which might be usefully used without the aid of computers if only a limited number of buildings are going to be examined). In considering

these various approaches to energy analysis it should be realized that there is no substitute for a good understanding of building and HVAC system operation. None of these programs can make up for a lack of background in the basics. All the analysis procedures must be viewed as tools, and like all tools, their usefulness depends entirely on the skill of the user.

Level 1 Analysis (Non-computerized analysis)

At this level the energy audit analysis would begin with monthly utility billings and a survey of direct energy use. The difference between total consumption and direct use is used to estimate the HVAC energy consumption. One then attempts to further estimate the energy used for the air distribution, heating, and cooling functions. If both the heating and cooling are served by the same energy source and no sub-metering or record of use is available, this may be rather difficult. However, with rated equipment capacities and estimates of operating hours, some division among the functions may be made. In such a situation, you should be more concerned with the relative magnitude of each energy use than the absolute level of consumption. If heating and cooling are derived from different sources, as is often the case, the process is generally simpler. Careful consideration of seasonal, or daily if available, variations in consumption can provide significant information.

In analyzing existing buildings physical plant personnel may encounter a difficult problem at this point -- the lack of metered information on individual buildings. Campus wide information on energy use is certainly of interest, but is of relatively little value when undertaking energy conservation projects. Specific information is required at least to the level of individual building consumption if a level 1 analysis is to be of any value. Level 2 and level 3 analyses would still be possible, but the lack of individual building consumption data will also reduce their effectiveness.

The installation of additional metering, if required, should be considered as an integral part of energy management projects.

The energy required for distributing chilled water, hot water or steam on campus and in buildings, and the energy required for air distribution within buildings must be carefully examined. The distribution energy requirement is usually a significant percentage of total energy use. It may be estimated by identifying the rated horsepower of the drive of pumps and fans in the distribution system and the operating schedule.

The energy consumped by the HVAC systems is related to the various components of heat gain or heat loss from the conditioned space. One further step in the analysis which may be of benefit is to estimate the source and magnitude of the components of heating and cooling load associated with the structure, with the ventilation and with the internal heat generation due to lights, equipment, etc. First of all, all the energy expended in operating lighting and equipment within the building is added as heat to the building. Approximately 85% of the energy input to the fans and pumps also shows up as heat added to the building. Energy from lights and equipment may well be the major sources of heat gain. The magnitude of this heat load can be determined from the audit data already gathered in the direct use survey.

A principal source of heat exchange between the building and its environment is the outside air brought into a building for ventilation purposes. The magnitude of the loads resulting from ventilation could be estimated with the help of nomographs based on wet bulb temperature which indicate heat gain and heat loss as a function of climatic and system parameters. Approximate values for the climatic variables can be obtained for a particular locality. Ventilation presents a significant opportunity for saving energy and should be examined carefully. The final component of load is that which is associated with heat transfer through the building envelop. Data from the building survey portion

of the audit and specific climatic data also provide a means of estimating these loads. At this level one might utilize heating/cooling load estimating procedures in the 1977 ASHRAE Handbook of Fundamentals or those outlined design manuals developed by Carrier, Trane and other manufacturers. For purposes of energy analysis, daily load are more indicative than peak hour (design) loads. A simplified procedure for estimating these daily loads is outlined in the appendix. In case of large buildings, particularly high rise, it is surprising how little the heat gained or lost through the envelop affects the total loads.

Level 2 Analysis (Energy audit and evaluation of conservation options)

A level 2 analysis would involve a much more careful examination of each of the load factors mentioned above. In the level 1 procedure, those heating and cooling loads related to environmental factors were assumed to be a function of a single variable or a combination of average values. However, the heat gain/loss through a wall is a function of the solar irradiation of the surface, the difference between the inside and outside temperature and both the thermal resistance and thermal capacitance of the construction materials used. Within the context of a Level 1 analysis, there is no means of dealing with the interaction of all these variables. At Level 2, one still does not attempt to deal with each in detail, but it is possible to obtain a more realistic result by means of computer analysis or through laborious hand calculations. At this level, one attempts to obtain estimates of

1) building heating and cooling loads
2) the energy requirements of components of the distribution system and of primary equipment such as boilers and chillers
3) annual building energy use.

Input to the analysis consists of description of the thermal characteristics of the building, occupancy and operating schedules, ventilation, and control and equipment performance. This requires relatively little information beyond that gathered for a Level 1 analysis. The output would provide a more detailed description of energy use within the building and thus provide a better basis for analyzing the possible benefits of energy management and conservation programs. As noted earlier, it is possible that some outside assistance may be required for a Level 2 analysis.

One characteristic difference between the types of programs that might be labeled Level 2 and Level 3 is the manner in which weather data and heating and cooling loads are handled. At Level 2 the number of calculations performed are reduced by grouping hours with "similar" loads where Level 3 utilizes 8760 hours of input in serial fashion. There has been, and will continue to be, considerable discussion as to the necessity of 8760 calculations. There are valid points on each side of the argument. However, the only relevant factors in the end relate to the cost/benefit of a particular program's use. This, or course, depends on the intended application of the energy analysis, and each type program has its place. However, if "in house" personnel are going to be responsible for the analysis and data preparation you may have to settle on one particular program simply due to the time required for training and familiarization with program characteristics.

One way a Level 2 analysis might group hours with similar load is by combining the "bin" dry bulb temperature data, such as provided "Engineering Weather Data" Air Force Manual 88-8, with operating schedules and estimates of coincident solar conditions for occupied and unoccupied periods for each month. It then is assumed that wet bulb and solar load correlate with the dry bulb temperature. In this case, some form of time averaged solar load is used. If the building

has a high mass and relatively large internal loads, this process is reasonable. The frequency of occurance of a particular load is thus based on the dry bulb temperature and whether the space is occupied or unoccupied.

A second method would be to use a "typical" day or days for each month and use the hourly load profiles of these days on a repetitive basis as input to system and equipment simulation procedures. Either of these procedures will reduce the number of load inputs to the system and equipment simulations by an order of magnitude or more.

Some Level 2 type programs emphasize the equipment and system aspects of the analysis and simplify the load inputs even further. These programs may use only design heating and cooling loads as input and not perform any load analysis at all. The peak (design) loads are used, with a scheme internal to the program, to estimate the variation of load with dry bulb temperature. This is then used as input to the system and equipment analysis. Such programs are of little value in those cases where the object is to evaluate methods of modifying space loads, but are useful if the system and equipment are the focus of the analysis.

At Level 2 one might again utilize heating/cooling load estimating procedures in the 1977 ASHRAE Handbook of Fundamentals based on ASHRAE sponsored research at the University of Pittsburg or those outlines in design manuals developed by Trane and Carrier. For purposes of describing the operation of the system and primary equipment procedures presently under development by ASHRAE's Technical Committee on Energy Calculations (T.C. 4.7) could be used.

There are several commercially available programs that operate at Level 2. These programs may require less input and provide a less detailed output than the hour by hour programs which we will discuss under Level 3 analysis. Their applicability should be investigated carefully before launching into a Level 3 program, particularly by smaller institutions. This is not meant to imply that they should be chosen in preference to an hour by hour program, but only

that they should not be neglected in considering the available options for energy analysis.

Level 3 Analysis (Complete Load, System and Equipment Simulation)

Level 3 precedures are a more detailed expansion of the analysis described as Level 2. They generally require more input, a larger computer system and more expertise in both HVAC systems and computer applications for successful use. The simulation techniques are more detailed and consider a much wider range of operating and climatic conditions. The Level 3 analyses usually consider an 8760 hour annual cycle. Some still derive their hourly variable inputs from a few "typical" days for each month, but many develop their calculations from a selected "test reference year" of actual weather data. A variety of methods have been suggested for selecting the weather data input. Currently NOAA has applied a procedure developed by ASHRAE's Technical Committees 4.7 and 4.2 to select TRY years for 60 U.S. Cities. (Information on these data may be obtained from the Director, National Climatic Center, Asheville, N.C. 28801. See also the February 1977 issue of the ASHRAE Journal, p. 47.)

A specification of a Level 3 analysis program capability would indicate the following:

a) The building heating/cooling load calculations would be of sufficient detail that the effects of variations in all building data (such as orientation, configuration, and thermal characteristics) and climatic data could be evaluated on an hour by hour basis.

b) The calculation procedure used to simulate the operation of building systems and component equipment would be of sufficient detail to permit the evaluation of the effects of system design, climatic factors, operational characteristics, and mechanical equipment over a full year operating period of 8760 hours.

These procedures would explicitly include the following:

a) Climatic data: coincident hourly data for temperatures, solar radiation, and humidity
b) Building data: orientation, size, shape, mass and air, moisture and heat transfer characteristics
c) Operational Characteristics: temperature and humidity levels, ventilation, illunination and control modes for occupied and unoccupied hours.
d) Mechanical equipment: capacity and part load per formance characteristics
e) Internal heat generation: lighting, equipment, and occupancy for occupied and unoccupied periods.

It is important to realize that the Level 3 programs do not utilize these data simply to perform a series of steady state design calculations extended over off-design conditions. They are dynamic to the extent that they account for the time sequence of space loads and building operating schedules. (Very few programs have, however, progressed to the point of considering the dynamics of control action or equipment performance which take place on a time scale of minutes rather than hours. This type of analysis may develop in the future, but it does not appear practical for anything other than research applications at present.)

The complete load and simulation programs, if properly designed, can serve the needs of both a general pre-design analysis of new buildings and of analysis of existing buildings for evaluation of refit options. As noted earlier, these two analysis functions have quite different requirements, but there is no inherent reason a single program cannot serve both needs.

Dr. Kusuda of the National Bureau of Standards and others have pointed out that an ideal program of this type would have the following characteristics:

a) well documented
b) simple and clear input
c) good diagnostic routine

d) standard data file and default options
e) numerous input options for building, system, and equipment components
f) flexibility for combining components
g) dynamic load calculations
h) ability to predict variation in space condition
i) numerous control options
j) ability to simulate alternative systems such as natural ventilation and illunination or heat recovery
k) complete energy use analysis
l) life cycle cost/economic analysis
m) simple and clear output at all levels of detail
n) fast
o) inexpensive

Perhaps some day such a program will exist. (Dr. Kusuda predicts that it will within 10 years). At the present, one must examine the existing programs and judge how well each might measure up to the ideal described above.

The major advantage of the Level 3 analysis is that once the simulation has been set up, parametric studies become possible. In a parametric analysis, one can easily vary such building features as materials, glazing, external shading, or orientation as well as system type, control and operating schedule, once the basic input data has been put into the computer. This flexibility makes it possible to easily extend the energy audit to the stage of evaluating conservation opportunities, which is the primary function of most energy analysis projects.

Many complex programs require little more input information than the less sophisticated programs. Their output is, however, so flexible that there is often a temptation to produce so much information that the task of interpreting and utilizing the results becomes a serious problem. This is a correctable fault and mentioned only to serve as a caution.

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has compiled a Bibliography on Available Computer Programs in the General Area of Heating, Refrigerating, Air Conditioning and Ventilating which describes a number of energy analysis programs. Examples of the bibliographic citations are included as Figures 2.1 and 2.2. These programs provide various levels of output information ranging from hourly space and equipment loads to daily, monthly, or annual summaries of energy consumption. Figure 2.3 illustrates tabular data output from one program.

Figure 2.1

NASA'S ENERGY COST ANALYSIS PROGRAM
(Code Name: NECAP)

PURPOSE: Determine building energy consumption. Cost analysis.

KEY WORDS: Energy analysis, Economic comparison, System simulation, Load calculation

DESCRIPTION: The NECAP program follows the procedures outlined in the ASHRAE booklet "Procedures for Determining Heating and Cooling Loads for Energy Calculation" to estimate the energy requirements for buildings. The program is actually a set of six individual computer programs including (1) a Response Factor program (2) a Data Verification program (3) a Thermal Loads Analysis program (4) a Variable Temperature program (5) a System and Equipment Simulation program and (6) a Owning and Operating Cost program. Standard wall construction and schedules can be used to simplify program input. The program is an extension of the Energy Utilization Program developed for the U.S. Postal Service, but incorporates extensive modification to improve its usability including completely revised documentation.

INPUT REQUIREMENTS: Building parameters, building coordinate system, azimuth angle, surface description and tilt angle, floor, ceiling, furnishing data, space description, thermostat schedules, type of energy distribution system and pertinent parameters, cost information.

PROGRAM OUTPUTS: Response factors if requested, summary of design day weather, space and building loads, surface shadow pictures and shadow calculations, recommended space heat extraction and addition rates, variable temperature loads if requested, zone air flows, summary of loads not met, equipment capacity summary, monthly and annual energy summary.

PROGRAMMING LANGUAGE: FORTRAN IV

SYSTEM COMPATIBILITY: CDC 6400, 6600

DEVELOPER: Gard, Inc. under contract to the National Aeronautics and Space Administration, Langley Research Center.

AVAILABILITY: Program is available through

COSMIC
Suite 112
Barrow Hall
University of Georgia
Athens, Georgia 30602
Ph. (404) 542-3265
Attn. Ron English

For more information contact:

R. N. Jensen
Technical Assistant
Construction Engineering Branch
Mail Stop 227
Langley Research Center
Hampton, Virginia 23665

Figure 2.2

NATIONAL BUREAU OF STANDARDS LOAD DETERMINATION PROGRAM (Code Name: NBSLD)

PURPOSE: Calculate heating and cooling loads in buildings and room temperature fluctuation.

KEY WORDS: Heating loads, Cooling loads, Load calculation, Energy analysis.

DESCRIPTION: NBSLD calculates the hour-by-hour heating and/or cooling load in buildings. The program utilizes the thermal response factor technique for calculating transient heat conduction through walls and roofs. The program also includes a routine which can calculate the "floating" temperature of those rooms with little or no air-conditioning and natural ventilation.

INPUT REQUIREMENTS: Building parameters such as wall properties, ceiling and floor properties, window area and location, operating schedules. Weather data from U.S. Weather Bureau tapes.

PROGRAM OUTPUTS: Hour-by-hour heating or cooling loads and temperatures for each zone for the entire year. Design day data may be examined as an option.

PROGRAMMING LANGUAGE: FORTRAN V

DEVELOPER: T. Kusuda - National Bureau of Standards

DATE AND STATUS: NBSLD was written in 1972 and is continually being revised.

DOCUMENTATION: NBSIR 74-574, "NBSLD, Computer Program for Heating and Cooling Loads in Buildings", 1974, and ASHRAE bulletin entitled, "Algorithms for Building Heat Transfer Subroutines", 1975.

AVAILABILITY: Source code and documentation may be obtained. For more information contact:

James P. Barnett
Thermal Engineering Section
Center for Building Technology, IAT
National Bureau of Standards
Washington, D. C. 20234

BUILDING LOAD SUMMARY FOR
LRC SYSTEMS ENGINEERING
HAMPTON, VIRGINIA

PAGE 7

SPACE NOS. 1 THRU 6

TOTAL FLOOR AREA (SQ.FT.) 53000.

TOTAL VOLUME (CU.FT.) 486800.

SUMMER COOLING PEAK
OUT/WBT/HR OF DAY/DATE 93 / 81 / 17 / AUG. 2

WINTER HEATING PEAK
OUT/WBT/HR OF DAY/DATE -15 / -15 / 6 / JAN. 23

	***** SUMMER LOAD ***** SENSIBLE (BTUH)	LATENT (BTUH)	WINTER LOAD (BTUH)
WALLS	4536.	0.	-109526.
CEILINGS	108050.	0.	-337488.
WINDOW CONDUCTANCE	54813.	0.	-344317.
WINDOW SOLAR	38664.	0.	0.
QUICK SURFACES	0.	0.	0.
INTERNAL SURFACES	7280.	0.	7280.
UNDERGROUND WALLS	0.	0.	0.
UNDERGROUND FLOORS	13738.	0.	-174599.
OCCUPANTS	85080.	67716.	75.
LIGHT TO SPACE	579218.	0.	16470.
EQUIPMENT TO SPACE	0.	0.	0.
INFILTRATION	0.	0.	0.
SUBTOTAL	890779.	67716.	-946106.
RETURN AIR	103640.	0.	2251.
FAN HEAT	68029.	0.	68029.
VENTILATION AIR	111764.	316788.	-729386.
TOTAL	1174211.	384504.	-1605210.

TOTAL BUILDING COOLING 1558714. BTUH 129.9 TONS
TOTAL BUILDING HEATING -1605210. BTUH -1605.2 MBH

	******* VARIABLE VOLUME SYSTEM *******		******* CONSTANT VOLUME SYSTEM *******	
SUPPLY AIR AT 55 F AT DIFFUSER	36497. CFM	0.69 CFM/SQ.FT. MAX.	42370. CFM	0.80 CFM/SQ.FT. CONST.
SUPPLY AIR AT 55 F AT DIFFUSER	45621. CFM	0.86 CFM/SQ.FT. MAX.	52962. CFM	1.00 CFM/SQ.FT. CONST.
SUPPLY AIR AT 120 F AT DIFFUSER	16500. CFM	0.31 CFM/SQ.FT. MAX.	17608. CFM	0.33 CFM/SQ.FT. CONST.
SUPPLY AIR AT 140 F AT DIFFUSER	11423. CFM	0.22 CFM/SQ.FT. MAX.	12190. CFM	0.23 CFM/SQ.FT. CONST.

Figure 2.3a Sample Output-Level III Analysis - NECAP

EQUIPMENT AND ENERGY CONSUMPTION ANALYSIS	FACILITY/ADDRESS: LRC SYSTEMS ENGINEERING, HAMPTON, VIRGINIA	DATE/PROJECT: NOV 26, 1975; SZ, 4W, 3IN	USER AND SYSTEM IDENTIFICATION: M.JEUTEN; SYSTEM NO. 102

ENERGY CONSUMPTION

	JAN.	FEB.	MARCH	APRIL	MAY	JUNE
MONTHLY BTU/1000						
MAX. DEMAND	-489.7	-420.1	-295.1	-60.3	-0.0	-0.0
CONSUMPTION	-191045.1	-155726.3	-114348.4	-60.4	-0.1	-0.0
MAX. DEMAND	0.0	0.0	0.0	1351.6	1586.2	2104.3
CONSUMPTION	0.0	0.0	0.0	43153.9	86051.1	316318.8
ELECTRICITY						
LIGHTS AND BUILDING EQUIPMENT						
INTERNAL						
DEMAND(KW)	212.0	212.0	212.0	212.0	212.0	212.0
CONS.(KWH)	51304.0	44308.0	48972.0	51304.0	51304.0	46640.0
EXTERNAL						
DEMAND(KW)	0.0	0.0	0.0	0.0	0.0	0.0
CONS.(KWH)	0.0	0.0	0.0	0.0	0.0	0.0
HEAT (INCL. BOILER AND AUXILIARIES, AND HOT WATER PUMPS						
DEMAND(KW)	5.2	5.2	5.2	5.2	5.2	5.2
CONS.(KWH)	3729.7	3481.1	3185.8	2227.5	1434.9	150.2
COOL (INCL. CHILLERS, WATER PUMPS, AND COOLING TOWER FAN						
DEMAND(KW)	0.0	0.0	23.2	92.8	97.3	128.6
CONS.(KWH)	0.0	0.0	2999.2	9135.4	15766.8	33759.0
FANS						
DEMAND(KW)	40.8	40.8	40.8	40.8	40.8	40.8
CONS.(KWH)	29354.3	27397.4	30332.8	29354.3	30332.8	29354.3
TOTAL						
DEMAND(KW)	258.0	258.0	276.0	345.6	350.1	381.4
CONS.(KWH)	84387.9	75186.4	85489.7	92021.1	98838.4	109843.4
GAS						
HEAT						
DEMAND(THERMS)	6.1	5.3	3.7	0.8	0.0	0.0
CONS.(THERMS)	2388.2	1946.7	1429.4	0.8	0.0	0.0
COOL						
DEMAND(THERMS)	0.0	0.0	0.0	0.0	0.0	0.0
CONS.(THERMS)	0.0	0.0	0.0	0.0	0.0	0.0
GENERATION						
DEMAND(THERMS)	0.0	0.0	0.0	0.0	0.0	0.0
CONS.(THERMS)	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL						
DEMAND(THERMS)	6.1	5.3	3.7	0.8	0.0	0.0
CONS.(THERMS)	2388.2	1946.7	1429.4	0.8	0.0	0.0

Figure 2.3b: Sample Output - Level III Analysis - NECAP

SECTION III

ENERGY ECONOMICS AND LIFE CYCLE COST ANALYSIS

OUTLINE

Introduction

Classification and Definition of Cost

Mathematics of Cost Comparison
Time Value of Money

Methodology for Evaluating Cost

Application Strategy

Summary and Conclusions

ENERGY ECONOMICS AND LIFE CYCLE COST ANALYSIS

Although we currently have the capability for determining either the actual (by utility bills) or the projected (by computer simulation) magnitudes of energy consumption by energy type in a building, in reality the major concern to any operator is cost. A methodology for evaluating and comparing energy costs, "first costs," maintenance cost and other associated expenses is the only objective way to develop management alternatives and make rational decisions to reduce total cost. Energy cost or consumption is only one element of total cost and is not in itself a satisfactory financial criterion. Such a systematic methodology is life cycle cost (LCC) analysis.

A life cycle cost analysis represents an attempt to evaluate--objectively--all significant costs: those associated with construction, owning, operating or maintaning a building over its projected economic life. The major weaknesses of this concept are: (1) that it projects future costs based on past information; (2) that it cannot properly reflect non-uniform changes in rate structures, e.g. recent utility rate changes; and (3) it cannot account for catastrophic operating or maintenance problems or failures that may infrequently occur. However, with all its shortcomings, it does yield a quantative, comparative cost index that is necessary for intelligent and reasonable management decisions associated with owning and operating a building.

Paramount and preliminary to any discussion of total costs is a definition of type of costs. Equally important is some understanding of the influence on or magnitude of the contribution to total cost that each component, by type, contributes to the "total cost." Once these two factors are established, a strategy can be developed for analysis and ultimate reduction of total cost.

Classification and Definition of Costs

Costs can be classified as investment, operating or owning costs.

I. Investment Costs

Investment costs or "first costs" include all purchase, installation and interim financing costs associated with construction. They can be considered to consist of those costs incurred prior to the time of permanent financing of a building. They include:

- Purchase cost of
  - land and land acquisition,
  - design of facility,
  - all materials of construction to include
    - * freight,
    - * sales tax,
    - * temporary storage cost,
    - * building or inspection fees; and
- Installation cost of:
  - the building and its
    - * plumbing,
    - * electrical,
    - * heating and
    - * cooling subsystems.

Typically these types of cost are evaluated only on the basis of capital cash outlay and purchase by a purchasing agent or others is based on competitive unit price. While it is mandatory that purchases and capital expenditures be made on a competitive price basis, another constraint on the type of equipment purchased and installed should be the associated owning and operating costs.

The "first" cost of a building is probably the easiest type cost to define. Certainly before the construction commences on a building--especially one that has been competitively bid--these costs are established. Inherently, these costs are determined by and subject only to current market supply and demand.

II. Operating and Owning Cost

The term "operating cost" as used herein normally includes:

- Energy cost
- Maintenance cost
- Service cost
- Energy demand cost or other similar costs associated with cash flow "burdens."

Separate, but with occasional overlap from operating cost, are owning costs. Owning costs normally include:

- Interest cost associated with long term financing
- Debt repayment
- Investment tax credits
- Real estate taxes
- Insurance costs.

In some instances, the classification of a cost as an operating cost or as an owning cost may be subject to interpretation. This is true with insurance cost and real estate taxes, especially as it concerns building ownership by private investors. Governmental agencies are generally not concerned with taxes, are self-insured, and money is secured by appropriation wherein inflation may or may not be a consideration. While first cost can generally be defined on the basis of competitive bids, each type of owning cost and

especially each type of operating cost should be calculated and considered separately. Total costs based on owning and operating costs should reflect escalation and inflationary increases that may or may not be increasing at uniform rates for each contributing element of the total cost.

Mathematics of Cost Comparisons - Time Value of Money

An engineering economic study should establish the most advantageous investment from among the many alternatives available. To accomplish this some basis for comparison must be established that will provide a measure of the significant difference between investment alternatives. The various alternatives must be reduced to a common base so that the apparent differences become real differences, with the time value of money considered, that can be directly compared during decision making. The most common bases for comparison are the present worth amount, the annual equivalent amount, the capitalized equivalent amount, the future worth amount, and the rate of return. Others are the payout period and the prospective value. Before any of these can be discussed the concept of time value of money must be understood.

As a simple example of the concept of the time value of money assume that $100 has been borrowed at 9% interest for a period of five years and that one single payment is made at the end of the period. The single payment would be computed as follows:

Interest Period Number				
1	P	$+ P_i$	$= P + P_i$	$= P(1 + i)$
2	$P(1 + i)$	$+ P(1 + i)i$	$= P(1 + i)i$	$= P(1 + i)^2$

$$3 \quad P(1+i)^2 + P(1+i)^2 i = P(1+i)^2 + P(1+i)^2 i = P(1+i)^3$$

$$4 \quad P(1+i)^3 + P(1+i)^3 i = P(1+i)^3 + P(1+i)^3 i = P(1+i)^4$$

$$5 \quad P(1+i)^4 + P(1+i)^4 i = P(1+i)^4 + P(1+i)^4 i = P(1+i)^5$$

.

.

$$n \quad P(1+i)^{n-1} + P(1+i)^{n-1} i = P(1+i)^{n-1} + P(1+i)^{n-1} i = P(1+i)^n = S$$

Thus,

$$S = P(1+i)^n \qquad (1)$$

where,

i = interest rate

n = number of interest periods

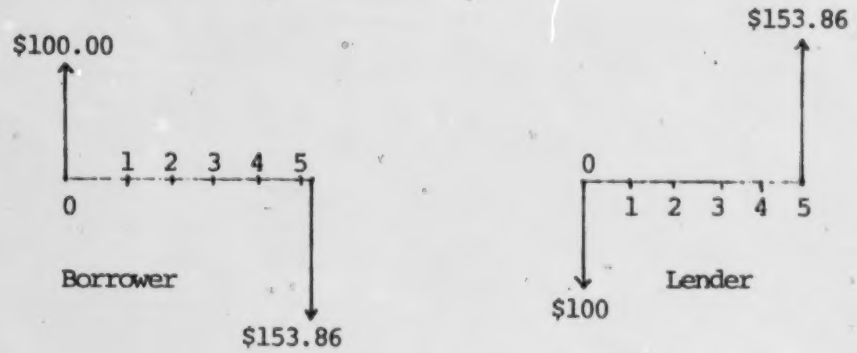
P = a present princial sum

S = a future sum, n periods in the future.

The factor $(1+i)^n$ is the single-payment compound amount factor (CAF).

When performing studies to evaluate the advisability or consequences of a particular investment it is often desirable to isolate each element of cost from the whole. To do this it is necessary to consider all the disbursements associated with a particular expense.

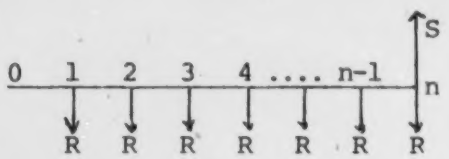
To aid in such an analysis a graphical representation of each alternative's cash transactions can be used. This graphical representation is referred to as a cash flow diagram. This diagram represents any receipts received over a period of time as an upward arrow located at the period's end with the arrows height proportional to the magnitude of the receipts received. Disbursements are represented by a downward arrow. These arrows are placed on a time scale representing the duration of the proposal. As an example consider the cash flow diagrams representing the previous transaction from the point of view of the borrower and lender.



Thus $100 now is worth $153.86 five years in the future if the interest rate is 9%. Conversely, the present worth of the $153.86 five years in the future is $100 computed from the relationship:

$$P = S \frac{1}{(1 + i)^n} . \qquad (2)$$

In many engineering studies, it is often desirable to determine the single future value that would accumulate from a series of equal payments occuring at the end of successive interest periods. The cash flow diagram for such an equal-payment series is presented below.



where,

R = the amount of a single payment in a series of n equal payments made at the end of each interest period, and

S = total future amount equal to the sum of individual future amounts calculated for each payment R.

Applying the equations $S = P(1 + i)^n$ to each of the individual payments starting with the first for n-1 interest periods, second for n-2 periods, etc.

$$S = R(1 + i)^{n-1} + R(1 + i)^{n-2} + R(1 + i)^{n-3} + \cdots + R(1 + i) + R.$$

Thus the total future amount S equals the sum of the individual future amounts of each payment. Multiplying this equation by (1 + i) results in

$$S(1 + i) = R(1 + i)^{n} + R(1 + i)^{n-1} + R(1 + i)^{n-3} + \cdots + R(1 + i)^{2} + R(1 + i)$$

Now if the first equation is subtracted from the second we arrive at an expression for S in terms of R and the interest rate.

$$S(1 + i) - S = -R \text{ or } S = R\left[\frac{(1 + i)^{n} - 1}{i}\right]. \qquad (3)$$

The bracketed term is the equal-payment-series compound-amount factor. (EPSCAF). This factor is used to find the compound amount, S, of an equal-payment-series, R. For example the future amount of $100 payments at the end of each of the next 5 years with an annual interest rate of 9% is,

$$S = \$100\left[\frac{(1 + 0.09)^{5} - 1}{0.09}\right] = \$100(5.985) = \$598.50.$$

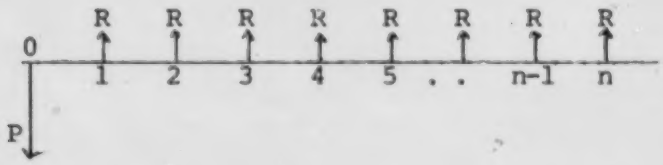
Solving the equal-payment-series compound-amount relationship for R yields:

$$R = S\left[\frac{i}{(1 + i)^{n} - 1}\right] = S(\text{EPSSFF}) \qquad (4)$$

The bracketed term is the equal-payment-series sinking-fund factor (EPSSFF) which can be used to find the year-end payments necessary to accumulate a future amount, S.

Now consider the deposit of an amount P in the present at an annual interest i. We wish to determine what amount can be withdrawn in a series of equal year-end amounts over the next n years to recover the principal plus earned interest with no funds left on deposit when the last withdrawal

is made. The cash flow diagram illustrating this case is shown below.



The problem is to relate R to P. This can be accomplished by eliminating S from the equations relating S and P, and S and R, i.e. equations (1) and (3). Thus,

$$P(1 + i)^n = R\left[\frac{(1 + i)^n - 1}{i}\right] \qquad \text{and,}$$

$$R = P\left[\frac{i(1 + i)^n}{(1 + i)^n - 1}\right] = P(\text{EPSCRF}) \tag{5}$$

The final bracketed term is the equal-payment-series capital recovery factor (EPSCRF). The reciprocal of this factor is the equal-payment-series present worth factor (EPSPWF) which can be used to determine the present worth, P, of a series of equal payments, R,

$$P = R\left[\frac{(1 + i)^n - 1}{i(1 + i)^n}\right] = R(\text{EPSPWF}) \tag{6}$$

Application of this relationship for comparing costs is discussed in the following section.

Methodology for Evaluating Cost

In the previous section the mathematicals tools for making a cost comparison among investment alternatives having equal service lives were developed. In general, investment alternatives have cost patterns that differ on a time basis, i.e. differing cash flows, but it is possible to

compute single equivalent amounts at any point in time that are equivalent in value to the particular cash flows. These equivalent amounts can be evaluated at a common point in time to provide an index for comparing alternative investment schemes. One such comparison index is the present worth amount, i.e. the common instant for comparison is the present.

The present-worth amount is that amount at the present that is equivalent to a cash flow at a particular interest rate i. A cash flow analysis lists the yearly expense cash flows, adjusted for present worth, for the various alternatives over the assumed life cycle of the system. The present-worth amounts of these cash flows can then be totaled to arrive at a total life cycle cash flow in terms of present worth dollars. This sum can then be added to the system's initial cost to arrive at a single value that can be used as an index to compare alternatives. The best investment will be that which results in the lowest total cost. If we assume that the yearly operating expenses for energy, maintenance, service, and energy demand are R_1, R_2, R_3 and R_4 respectively the total present worth of the operating expense is:

$$PW_{operating} = R_1(EPSPWF_1) + R_2(EPSPWF_2) + R_3(EPSPWF_3) + R_4(EPSPWF_4)$$

For the case of equal interest rates associated with each expense this reduces to

$$PW_{operating} = EPSPWF(R_1 + R_2 + R_3 + R_4)$$

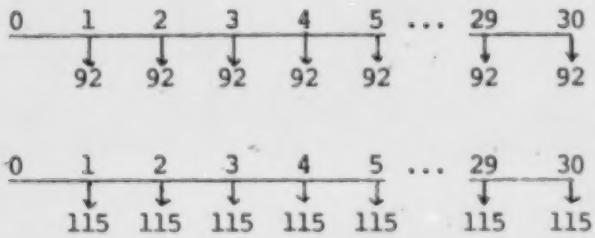
A uniform expense may be referred to as a uniform end-of-year cost. Actually the expense may be spread over the year, but is considered an equivalent end-of-year cost. The following example illustrates the cost comparison methodology based on present-worth-amount.

Assume that a building can be built for $750,000 with a type "A"

environmental control system and for $650,000 with a type "B" system. The expected life of the building in both cases is 30 years and money is worth 8.5% per year. The following costs are assignable to each system.

	"A"	"B"
First Cost	750,000	650,000
Energy Cost Per Year	75,000	100,000
Maintenance Cost Per Year	9,000	7,000
Service Cost Per Year	5,000	5,000
Energy Demand Cost Per Year	3,000	3,000

The total operating expenses are $92,000 and $115,000 for systems "A" and "B" respectively. The cash flow diagrams for each of these alternatives are shown below (amounts shown in $1000).



Equal-payment-series present worth factor:

$$EPSPWF = \left[\frac{(1.085)^{30}}{(0.085)(1.085)^{30}}\right] = 10.75$$

The present values at 8.5% of the 30 year total operating costs are computed as follows:

$$(PW)_A = (92{,}000)(10.75) = \$989{,}000$$

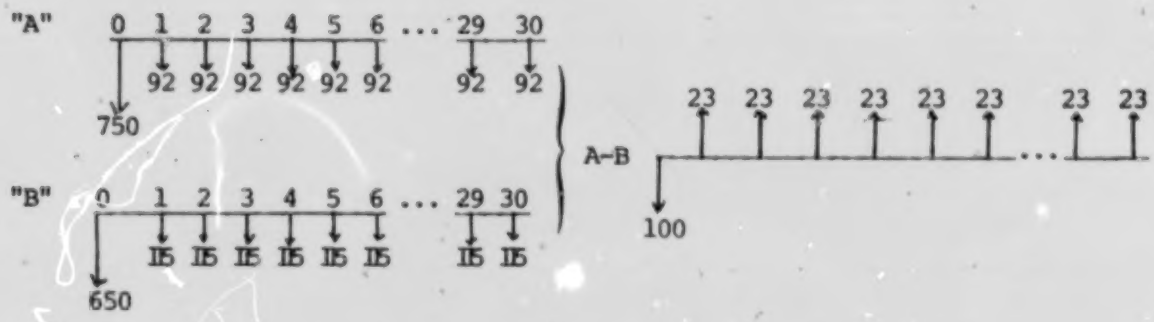
$$(PW)_B = (115{,}000)(10.75) = \$1{,}236{,}250, \text{ and}$$

the cost comparison is summarized below.

	"A"	"B"
Initial Investment	$ 750,000	$ 650,000
Present Value at 8.5% of 30 year operating costs	$ 989,000	$1,236,250
Total Life Cycle Costs	$1,739,000	$1,886,250
Savings with System A	——	$ 147,250

This simple example illustrates that although system "A" has the highest first cost, its life cycle cost is lower. Thus, system "A" would be the best choice from an economic standpoint. The difference between the two present worths can be interpreted as the present worth of an equal series of annual operating cost savings (equal to the difference between the annual operating expenses of the two systems) minus the additional original investment for system "A." That is, it is sufficient to analyze the cash flow that represents the difference between "A" and "B." This is shown in the table and diagrams below.

End of Year	Alternative "A"	Alternative "B"	Cash Flow Difference A-B
0	-750,000	-650,000	-100,000
1	- 92,000	-115,000	23,000
2	- 92,000	-115,000	23,000
⋮	⋮	⋮	⋮
30	- 92,000	-115,000	23,000



Present worth of equal savings series = ($23,000)(10.75) = $247,250

Saving over life cycle = $247,250 - $100,000 = $147,250.

This is the same life cycle savings previously determined.

Still another way of viewing the previous example is to convert the entire cash flow including the initial investment to a equivalent series of equal annual payments. This conversion is accomplished by first computing the present worth amount for the original cash flow (as done above) and then using equation (5) convert it to a uniform series. For the example discussed above,

$$\text{Equal payment-series-capital recovery factor} = \frac{(0.085)(1.085)^{30}}{(1.085)^{30}-1} = 0.093$$

Equivalent Uniform Annual Costs

R_A = $1,739,000(0.093) = $161,767

R_B = $1,886,250(0.93) = $175,421

Annual Savings With Alternative A = $13,694.

Ratio of Annual Costs = A/B = .922

Figure 1 illustrates the concepts that have been developed thus far. The contribution of each component of the operating and owning costs to the total life cycle cost and annual equivalent cost is shown as well as the relationship among them. Although only the interest and principal components

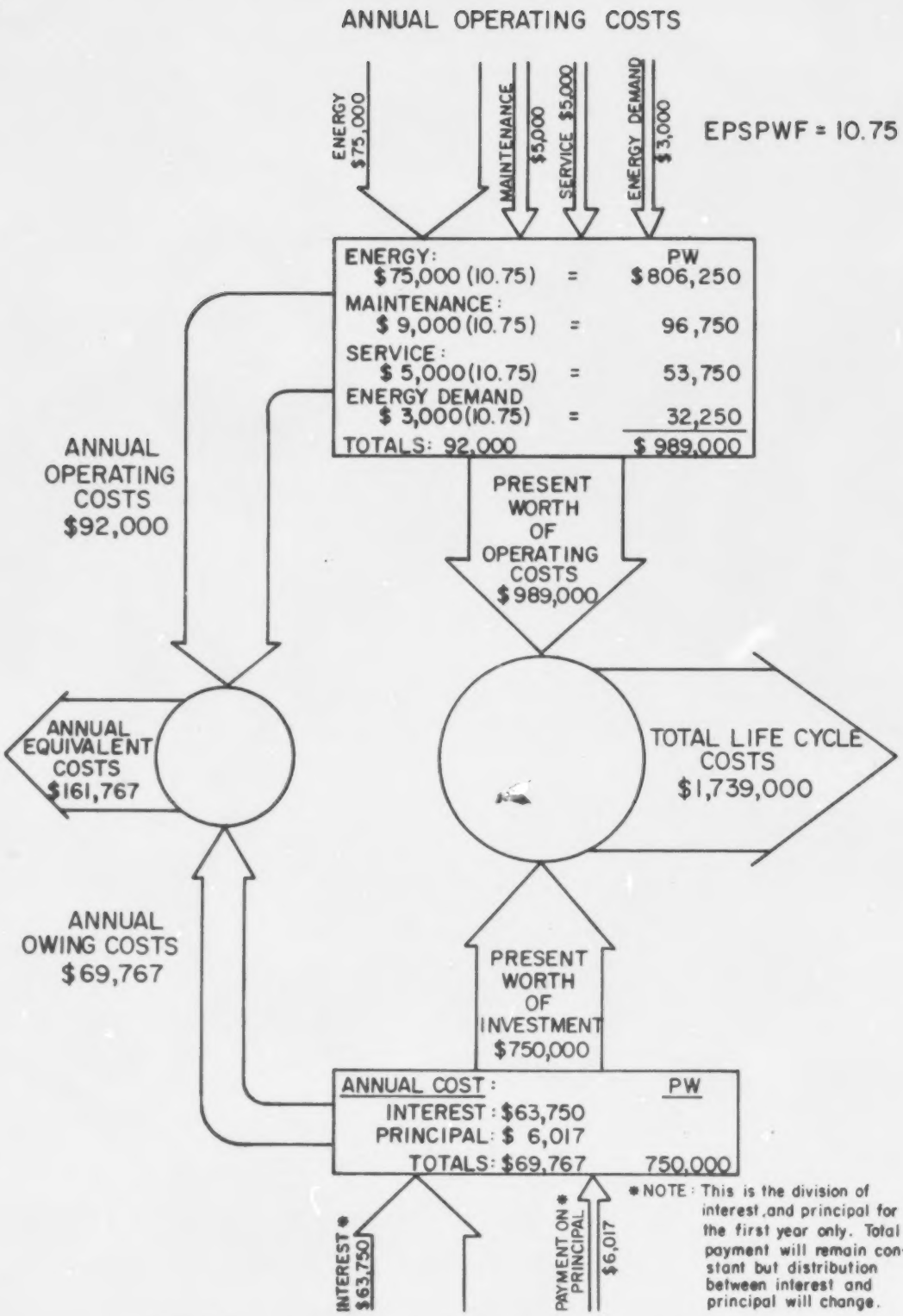

ANNUAL OPERATING COSTS
ENERGY $75,000
MAINTENANCE $5,000
SERVICE $5,000
ENERGY DEMAND $3,000
EPSPWF = 10.75
ENERGY: $75,000 (10.75) = PW $806,250
MAINTENANCE: $ 9,000 (10.75) = 96,750
SERVICE: $ 5,000 (10.75) = 53,750
ENERGY DEMAND $ 3,000 (10.75) = 32,250
TOTALS: 92,000 $ 989,000
ANNUAL OPERATING COSTS $92,000
PRESENT WORTH OF OPERATING COSTS $989,000
ANNUAL EQUIVALENT COSTS $161,767
TOTAL LIFE CYCLE COSTS $1,739,000
ANNUAL OWING COSTS $69,767
PRESENT WORTH OF INVESTMENT $750,000
ANNUAL COST: PW
INTEREST: $63,750
PRINCIPAL: $ 6,017
TOTALS: $69,767 750,000
INTEREST * $63,750
PAYMENT ON * PRINCIPAL $6,017
*NOTE: This is the division of interest, and principal for the first year only. Total payment will remain constant but distribution between interest and principal will change.

FIGURE I : COST RELATIONSHIPS FOR ALTERNATIVE "A".

of the owning cost are shown, cash flow analyses could be performed to account for taxes, insurance and other costs of ownership.

In some cases the "payback" or "payout" period is used as a means of evaluating an alternative. The payout period is generally defined as the length of time required to recover the first cost of an investment from the net cash flow produced by that investment for an interest rate equal to zero. For the examples of alternatives "A" and "B" the net cash flow in any year is \$115,000 - \$92,000 = \$23,000. Thus the payout period is:

$$n = \frac{\$100,000}{\$\ 23,000} = 4.3 \text{ years.}$$

This criterion gives some measure of the rate at which an investment will recover its original outlay except that it does not consider the time value of money. In other words it does not consider that the net saving each year could be put to some other use or be invested at the going rate of interest.

In many cases it is necessary to compare alternatives which have different service lives. When comparing alternatives of this type it is necessary that they all be compared over the same time span so that the effect of undertaking one alternative can be considered to be identical to the effect of any other. For example, the direct comparison of an alternative with a 10-year life and one with a 15-year life fails to consider the possible investment that could be undertaken following the first alternative's termination. One method of approaching this type of comparison confines the consideration of the effects of the alternatives to a particular study period usually taken to be the life of the shortest-lived alternative. That equivalent uniform annual cost is used to make the comparison. Consider the example of alternatives "A" and "B" with the exception that "A" has a life of

30 years, but "B" will last only 20 years. The annual equivalent amounts for the two cases are computed as follows:

R = Equivalent Annual Owning Cost + Equivalent Annual Operating Cost.

$R_A = \$760,000\ (EPSCRF)_{30} + \$92,000$

$R_A = \$750,000\ (0.093) + \$92,000 = \$161,767$ for 30 years.

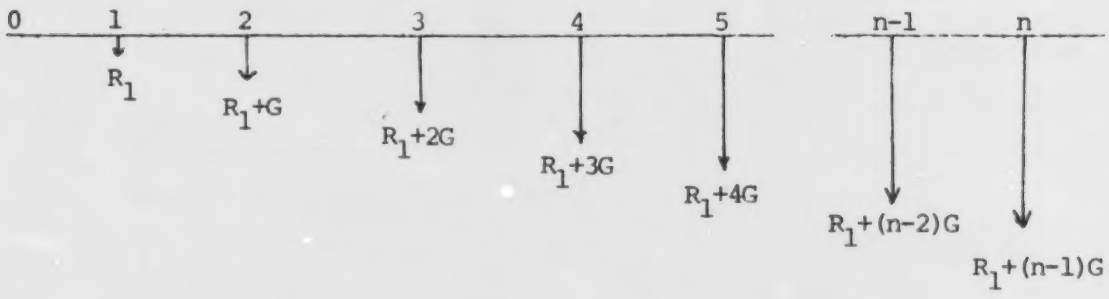
$R_B = \$650,000\ (EPSCRF)_{20} + \$115,000$

$$R_B = \$650,000\left[\frac{(0.085)(1.085)^{20}}{(1.085)^{20}-1}\right] + \$115,000 = \$183,686 \text{ for 20 years.}$$

Thus, for this case, the advantage of alternative "A" over "B" is $21,919 per year for the first 20 years. The costs for the period after the study period would be considered when comparing a successor to alternative "B" with the prospect of continuing alternative "A."

The foregoing examples have been stated assuming uniform annual costs whereas this is usually not the case, especially in this time of rapid inflation. Therefore no discussion of decision making based on costs would be complete without including the case of increasing costs. The methodology that has been presented is sufficiently general to deal with any scheme of increasing costs, for as was demonstrated any cash flow can be reduced to an equivalent single amount at any point of time. Thus if the expected cash flow can be defined it can be reduced to present worth or equivalent uniform annual cost, although the computations may be more tedious than those shown. The special case of uniform increasing costs is in many cases a good approximation considering the difficulty of predicting cost increases and a general equation is obtainable for evaluating such a case. In general a uniformly increasing series of payments may be expressed as R_1, $R_1 + R_G$,

$R_1 + 2G$, $R_1 + 3G$ ..., $R_1 + (n - 1)G$. The cash flow diagram for this uniform gradient series is shown below.



This series could be evaluated, as any cash flow could be, by applying the interest formulas to each payment in the series, e.g. the present worth of each payment could be computed using equation (2) and the sum of these amounts would then be the present worth of the entire cash flow. Such a computation would, however, be very time consuming unless a computer were available. An easier method would be to reduce the uniformly increasing series of payments to an equivalent equal-payment-series to facilitate the use of the equal-payment-series factors as illustrated previously. This can be done by considering the gradient series with equal payments R_1 and a gradient series 0, G, 2G, ..., (n-1)G. The present worth of the gradient series using equation (2) is

$$P = \left[G \frac{0}{1 + i} + \frac{1}{(1 + i)^2} + \frac{2}{(1 + i)^3} + \frac{3}{(1 + i)^4} + \ldots + \frac{(n - 1)}{(1 + i)^n}\right].$$

This reduces to $P = \frac{G}{i}\left[\frac{(1 + i)^n - 1}{i(1 + i)^n} - \frac{n}{(1 + i)^n}\right]$, and (7)

with the use of equation (5) is reduced to the equivalent uniform annual payment R_G,

$$R_G = \frac{G}{i}\left[\frac{(1+i)^n - 1}{i(1+i)^n} - \frac{n}{(1+i)^n}\right]\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

$$R_G = G\left[\frac{1}{i} - \frac{n}{(1+i)^n - 1}\right] = G\left[\frac{1}{i} - \frac{n}{i}\left(\frac{i}{(1+i)^n - 1}\right)\right]$$

$$R_G = G\left[\frac{1}{i} - \frac{n}{i}\,(EPSSFF)\right] , \qquad (8)$$

where, G = Annual change or gradient

n = Number of years.

$$EPSSFF = \frac{i}{(1+i)^n - 1} , \text{ and}$$

the bracketed term is the gradient factor. The annual payment R for an equal payment series equivalent to the uniformly increasing series is the sum of R_1 and R_G:

$$R = R_1 + R_G.$$

This same procedure can be followed for each of the expense cash flows. In some cases the rates of escalation of the various expenses may differ which would require a different value of G for each one. In any case the cash flows can be reduced to equivalent uniform-payment-series for use in the interest formulas and the analysis performed as outlined previously.

Application Strategy

The first step to be taken in performing a life-cycle cost analysis is to decide on the alternatives to be compared. This requires the application of criteria which consider the task which must be performed by the system, space limitations, availability of equipment, availability of maintenance and operation personnel and maybe even personal preference of the engineer, builder or building operator.

Once the alternatives have been defined cost information must be

assembled. That is for each alternative the following items must be defined:

- Initial purchase and installation costs (investment costs)
- Expected life time of each alternative
- Interest rate to be used--the cost of money
- Expected operating cash flows associated with each alternative
  - Energy
  - Maintenance
  - Service
  - Etc.
- Expected owning cash flow, i.e. mortgage debt if applicable
- Whether or not inflation rates are to be used and what they are for each of the cash flows
- Whether or not insurance is to be considered and rate if applicable
- Tax rates if applicable.

The investment costs are usually easily determined as they will be competitively bid. The expected life time of each alternative is more difficult to determine, but it can be estimated based on previous experience with similar systems and information supplied by manufacturers or consulting engineers. Since money invested in a building or equipment must be borrowed, obtained from investors or diverted from other prospective uses, it has value, and the interest rate reflects this value. Consequently, it represents the investor's best estimate of what money is worth to him. The remainder of the items listed above require an analysis of expected system performance and a judgement as to what the annual cash flow for each component of the total cost will be. These cash flows may be uniform annual payments or they may escalate over time. The investor must exercise care in

the estimation of these cash flows as they are often the deciding factor in choosing one alternative over others. Estimates of owning and operating costs must be a realistic assessment of the expected costs associated with each alternative over its entire life cycle.

After all of the items listed above are determined for the alternatives selected the methodology of the previous section may be used to arrive at a common basis for comparison. That is the cash flows are reduced to present-worth value and the total life cycle present worth value, (LCC) is computed. It must be recognized that if the service lives of the various alternatives are not equal the uniform equivalent cost method must be used to compare the alternatives over equal study periods.

The final step in the life-cycle cost analysis is to compare alternatives. This is done by comparing the total life cycle cost in present worth dollars or the annualized life cycle cost over the life cycle of the shortest lived alternative. A summary of the calculations similar to Figure 1 will provide the investor with a breakdown of his prospective costs and indicate the contribution of each cost component to the total life cycle cost.

Summary and Conclusions

Calculation of life cycle costs by the methods outlined above can be an involved and tedious procedure without the aid of a computer. Fortunately, computer codes have been developed that will perform such calculations. One such code was developed by NASA and is available to the general public. This program, NASA's Owning and Operating Cost Analysis Program, is written in Fortran and is simple to input and inexpensive to run.

The obvious drawback to the life cycle cost method is that the investor is faced with the task of supplying a considerable amount of "a priori"

information with regard to each alternative. Salvage values, equipment life and operating costs are difficult to project, especially in this era of rapid inflation and changing energy costs. This method, however, provides a means for making comprehensive, systematic assessments of alternative courses of action, through the development of a quantitative index by which alternatives can be compared. It will result in sound economic decisions well worth the effort expended if proper attention is paid to the reliability of the input data.

SECTION IV

INTERPRETATION AND APPLICATION OF RESULTS

OUTLINE

Load Calculations
- Glass
- Wall U Value
- Solar Load
- Thermal Load
- Internal Load

System Simulation
- Outside Ventilation
- Actual Load

Equipment Analysis

Summary

INTERPRETATION AND APPLICATION OF RESULTS

It is important that an energy analysis computer program have flexible output. It should be capable of presenting the data in both detail and summary fashion as requested. There are times when detail is required but in most instances the summary form will be most useful. In computer analysis it is quite possible to generate too much output, so much in fact, that the value of the analysis is completely lost. Success often depends on the ability of the user to identify real needs for information and avoid printing out data just because it is there. The developers of commercially available programs have given considerable thought to both input and output needs. They provide some guidance just by limiting the options available. However, the more flexible and comprehensive the program, the more output options available and the greater the responsibility of the user.

Load Calculations:

The load calculation programs provide a useful example. In the design phase, it is possible to initiate the analysis by considering a "typical floor" of a building, neglecting zoning and output only sums on heating and cooling loads. The impact of various configurations and materials combination can be evaluated quickly with little input. Figure 4-1 and 4-2 provide examples of this type data. The results shown are for a "typical floor" of a proposed office building

in Dallas, Texas. They indicate the influence of the amount and type of glass on peak and daily heating and cooling loads for a summer and a winter day.

At another level of detail, Figure 4.3 shows the results of varying the amount of single pane bronze tinted plate glass in a west facing zone. In Figure 4.4 the data compares the tinted glass with double pane reflective glass. One bit of information the data of Figures 4.1 to 4.4 illustrate is that variations in the architectural features of this building have a more pronounced effect on system capacity than on energy consumption. This data also shows percent variation in the winter is greater than the summer. Figure 4.5 is a similar illustration of the effect of reducing the opaque wall heat transfer coefficient U by improving the insulation. Although the U value was reduced almost 50%, the impact is much less than produced by varying the thermal characteristics of the glass.

Graphical output can be very useful in quickly pointing out problem areas. Figure 4-6 is a plot of the solar loads on a state office building adjacent to the University of Texas Campus in Austin. It is clear from this data that the peak solar load on a mild, sunny winter day is higher than the summer peak and that it is due almost entirely to the solar loads on the south zone. This fact is of critical importance in designing the air distribution system for the south facing zones of the building.

Figure 4-3: Daily Profile Of Space Loads For A West Facing Zone As A Function of % Glass

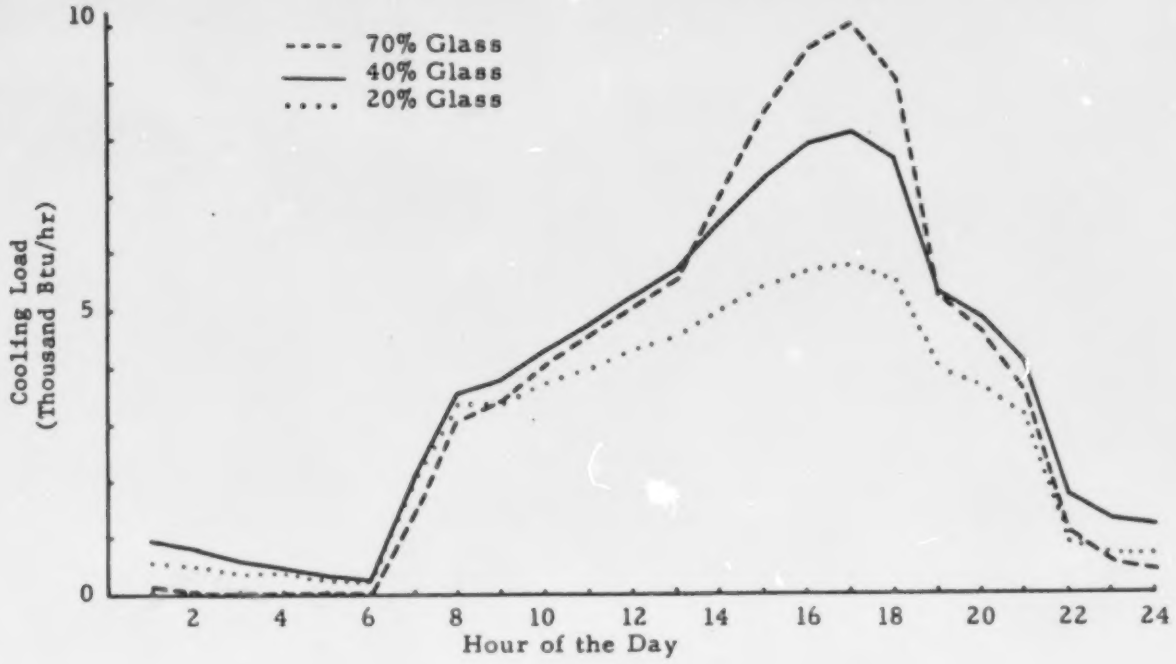


Figure 4-4: Daily Profile Of Space Load For A West Facing Zone As A Function Of Glass Type

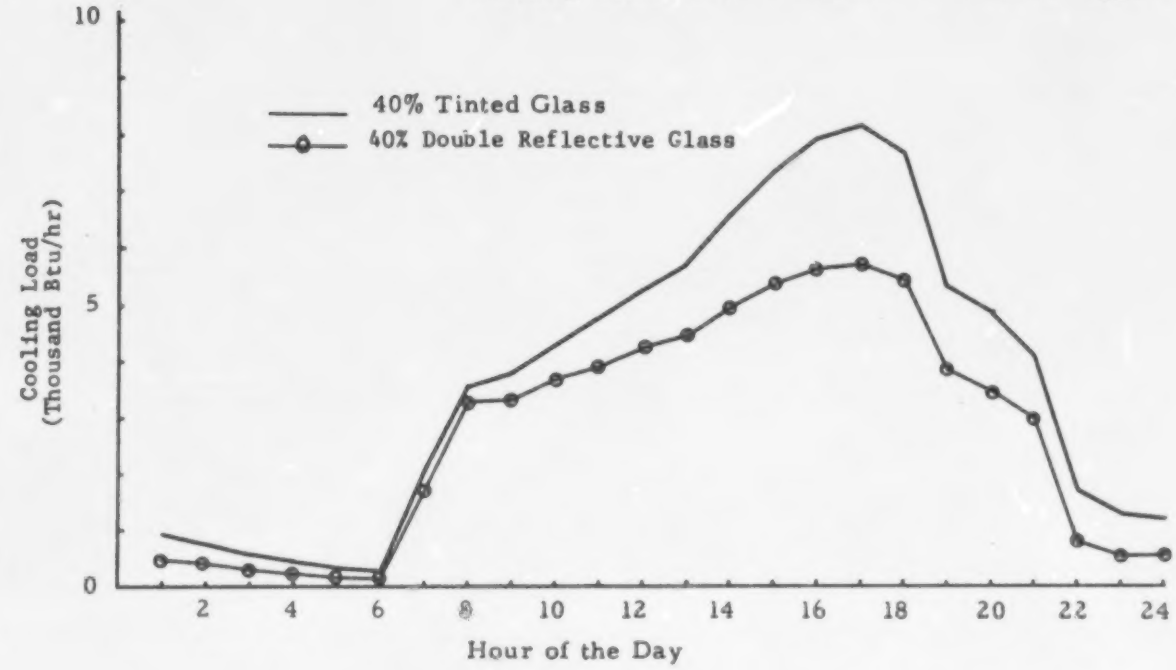


Figure 4-5: Daily Profile Of Space Loads For A West Facing Zone With 40% Glass As A Function Of Wall U Value

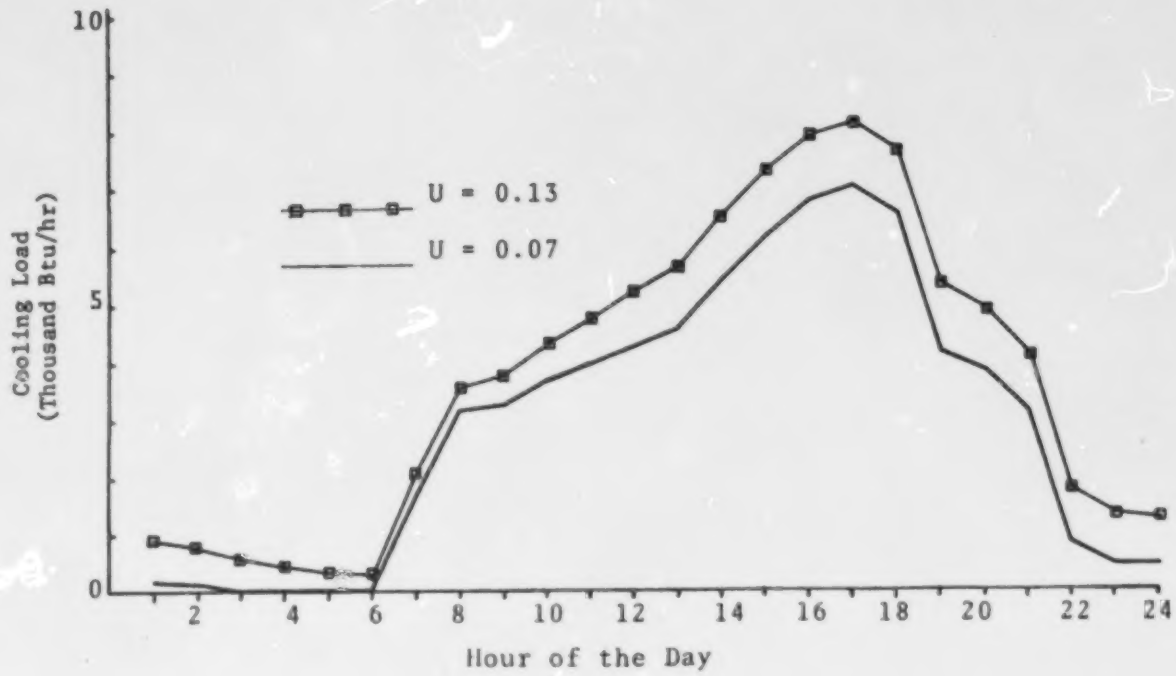
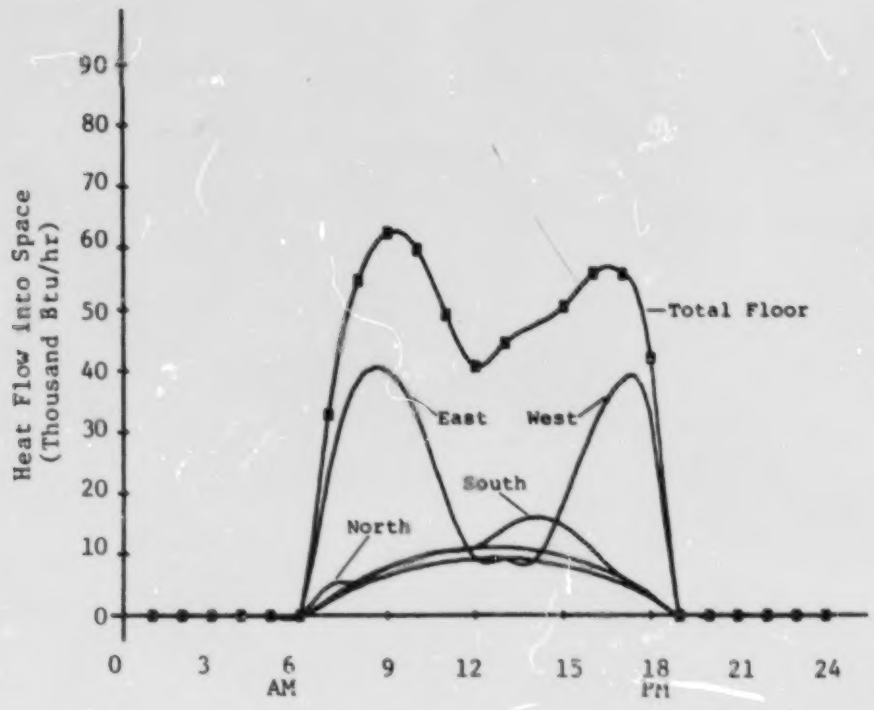
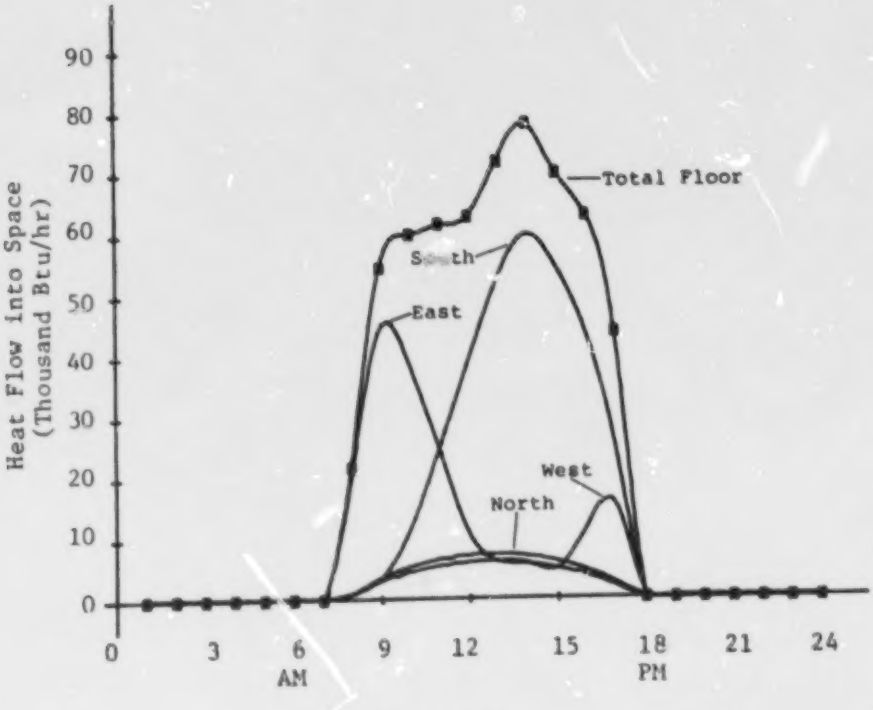


Figure 4-6: Daily Solar Loads On A Typical Floor Of An Office Building In Austin, Texas



SUMMER DAY



WINTER DAY

In existing buildings one will not usually be concerned with major architectural changes such as varying the amount of glass. However, the addition of shading or replacing existing window systems might be considered. In this case the load characteristics of the existing building should be examined before simulating the effects of modifications. For this analysis additional output may be required. For example, the heat gain or loss associated with walls, windows, ventilation and internal loads would indicate the amount of impact a change in one of these factors might have on energy requirements. Output from an analysis of the State Office Building indicated the distribution among load components shown in Table 4-1. These results show that a major expenditure to modify the windows would not be warranted.

Hourly profiles of loads may be useful in identifying conservation opportunities. Profiles for internal loads and total space loads are shown in Figure 4-7 and 4-8. The impact of internal loads is clearly evident in the space load profiles. These data indicate that reducing internal loads will have a greater effect on energy consumption than architectural changes. Graphical output of hourly profiles for specific days is useful, but hour by hour print out of such data over extended periods such as weeks or a month would be difficult to utilize effectively.

In a later stage of the design processes, when the distribution system is being sized, zoning is essential and it is necessary to print out peak loads for each zone. The

Table 4-1: Components Of Thermal Load Of An Office Building* On A Work Day (Btu/ft^2/Day)

	Summer Day	Winter Day
Lights	186	186
Fans & Pumps	98	98
Office Equipment	11	11
People	15	15
Total Internal		
Wall Transmission	17	-48
Window Transmission	19	-105
Window Solar	19	14
Total Envelope		
Total Ventilation	200	-210

* Building Characteristic
  Size: 380,000 ft^2, 12 stories, 1.3 aspect ratio
  Volume to Surface Area: 42 ft^2/ft^2
  Percent Wall Area in Glass: 30%

Figure 4-7: Daily Internal Load Profile For A Typical Floor Of An Office Building In Austin, Texas

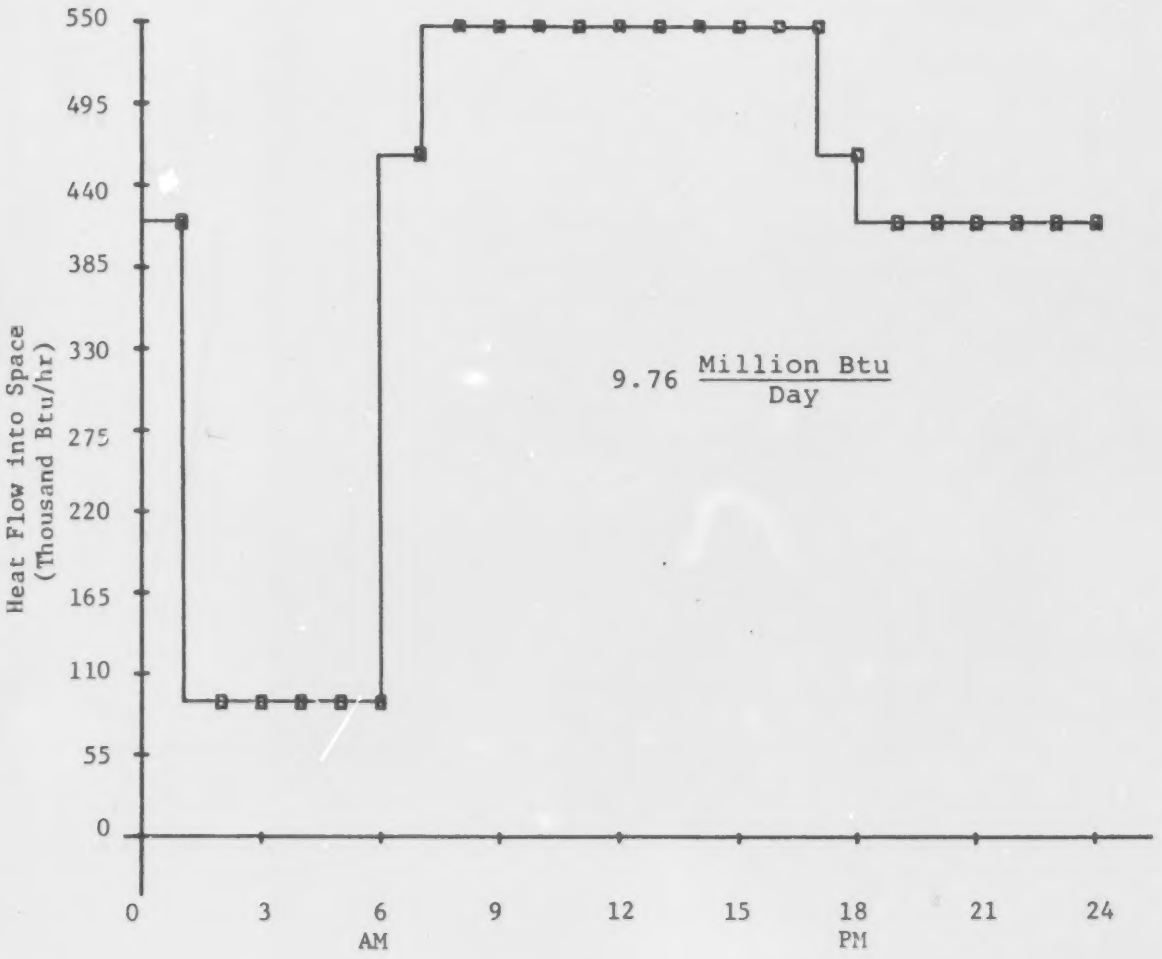
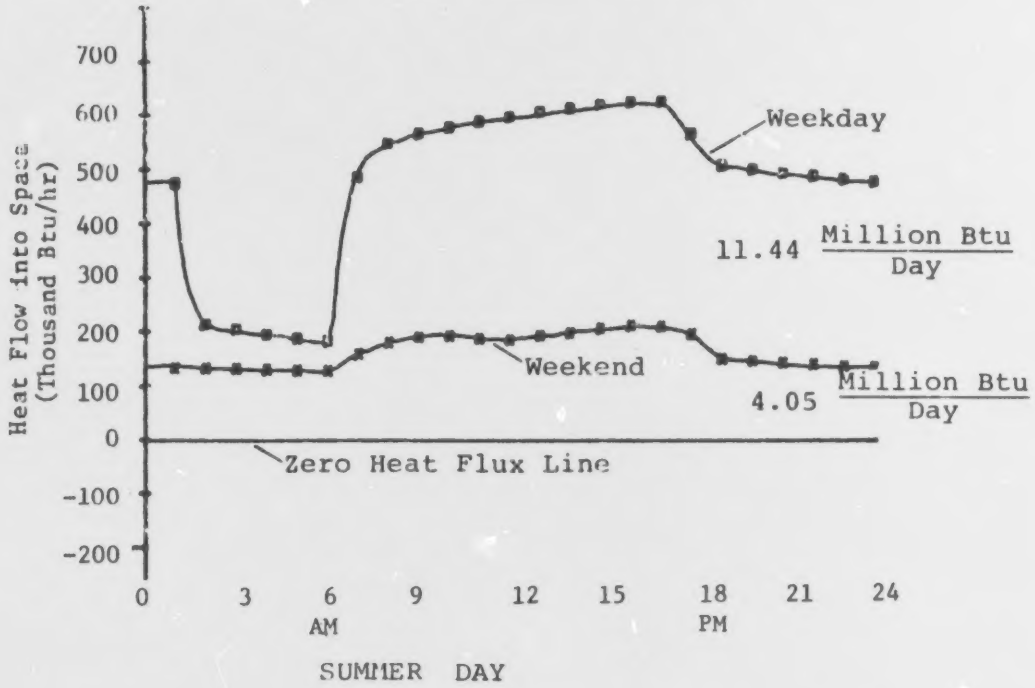
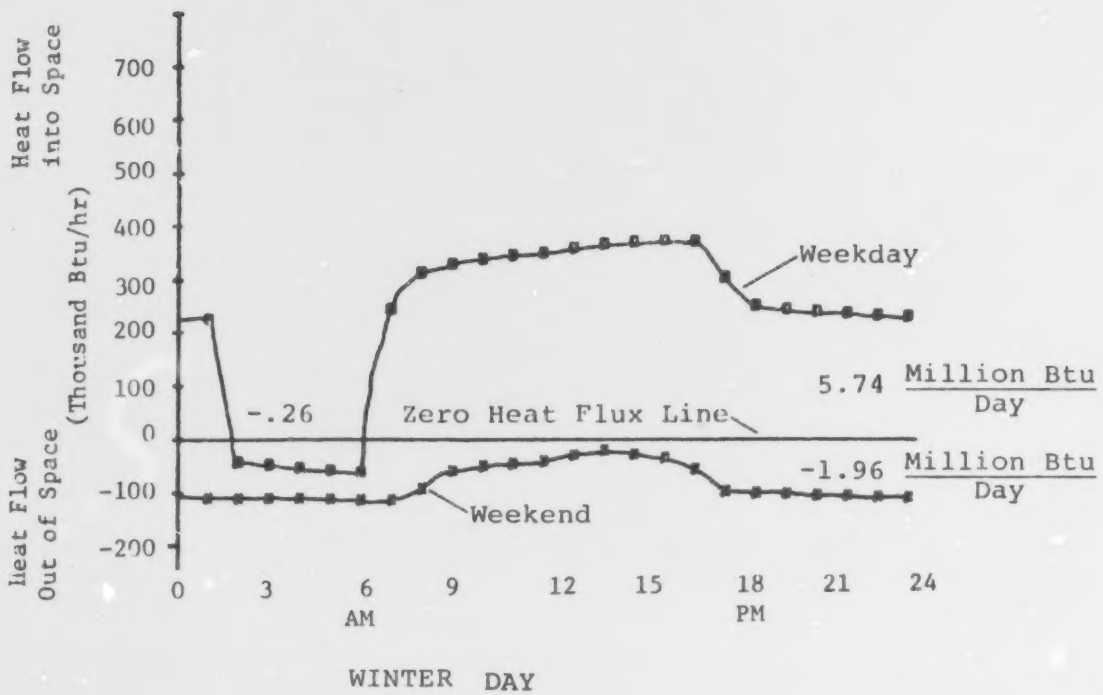


Figure 4-8: Daily Load Profiles For A Typical Floor Of An Office Building in Austin, Texas





program should be capable of indicating these peak loads without a serial listing of hour by hour output. However, when it is necessary to diagnose a particular problem (with either the program or the building), the program should have the ability to print out hourly loads and echo corresponding input data. In such cases hourly data may quickly reveal the difficulty, particularly if presented graphically.

System Simulation:

When it comes to system simulation, an entirely new set of output parameters become important and the details of the heating and cooling loads are no longer pertinent. As a matter of fact, once the space and ventilation loads have been evaluated and are stored for further reference, the time sequence of the analysis is of much less consequence. The time sequence is, however, generally preserved and carried through the analysis as a matter of convenience. The output of concern here is, for example, hours of operation, power requirements of fans and pumps and the loads on heating and cooling coils. It should be noted that this type of intermediate output may be of particular importance in analyzing campus buildings operating from central plant facilities. Some programs do not have this system component output capability at the present time. As examples of this type of data, again presented in graphical form, Figures 4-9 and 4-10 provide summaries of a daily ventilation load and daily heating and cooling coil energy requirements over

Figure 4-9

DAILY HEATING AND COOLING REQUIRED TO PRECONDITION
OUTSIDE VENTILATION AIR FOR THE BUILDING

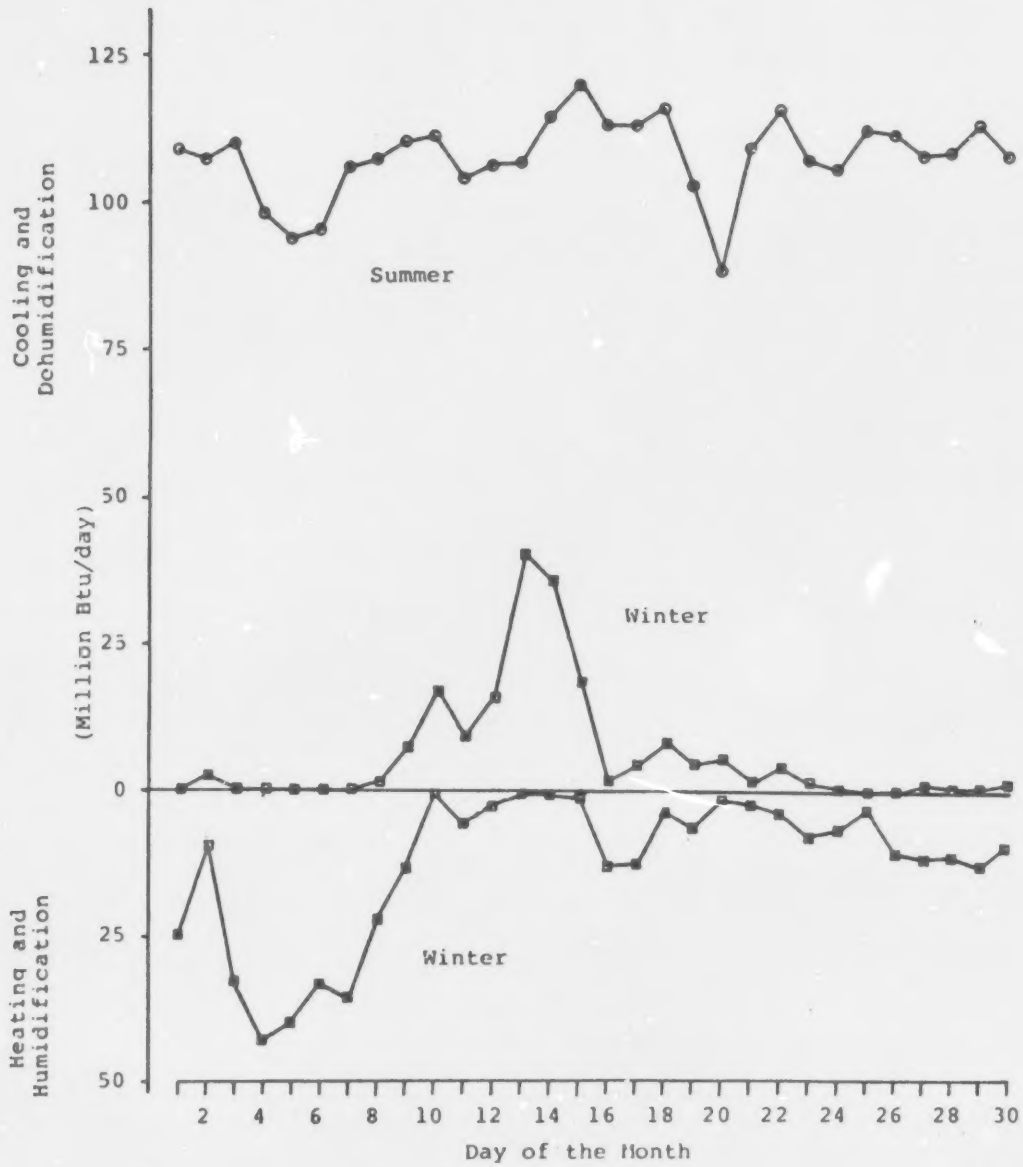
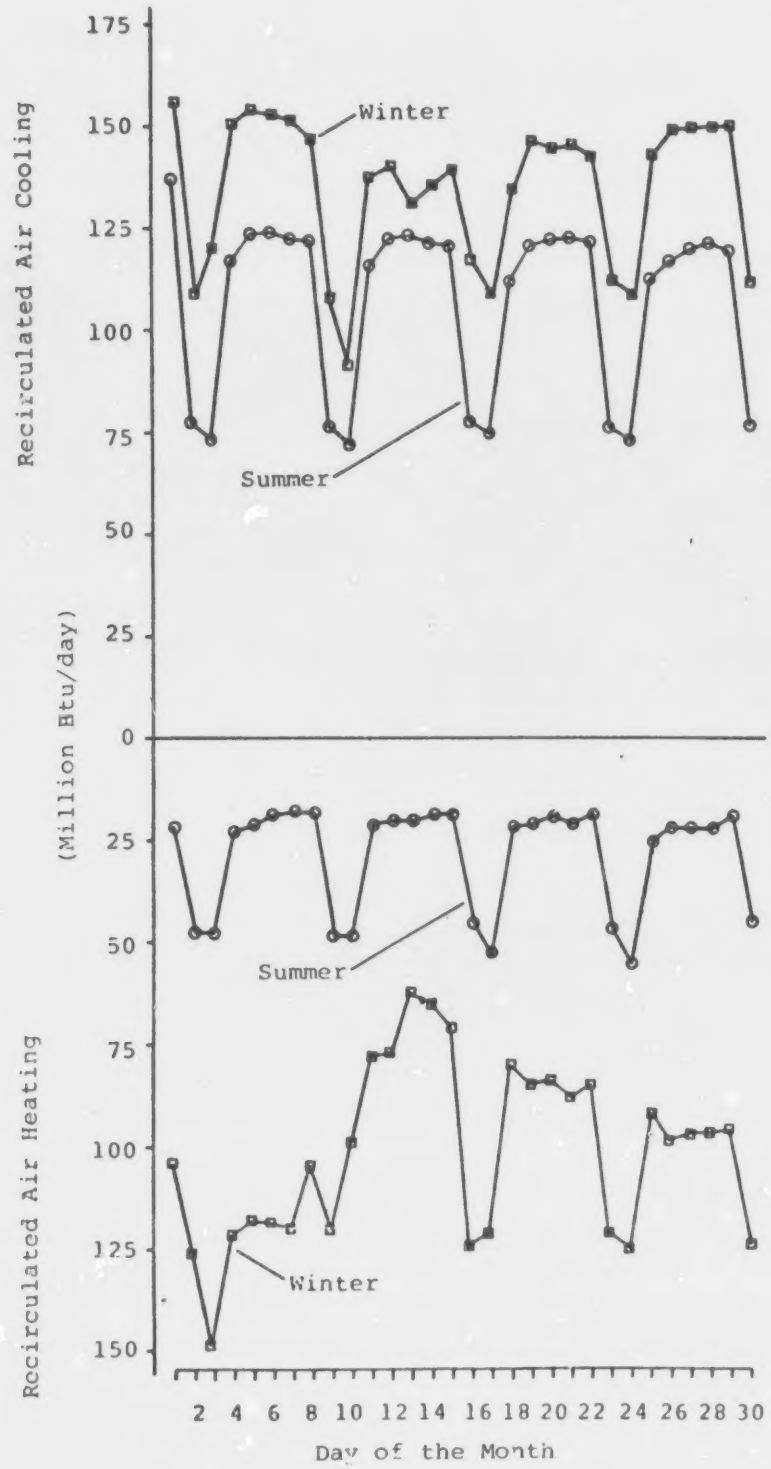


Figure 4-10

ACTUAL HEATING AND COOLING PRODUCED TO MEET
THE DAILY HEATING AND COOLING LOADS ON THE BUILDING



a month. Perhaps the most significant result of the Figure 4-9 data is the magnitude of the ventilation load. Of particular interest is the winter humidification load (winter latent load) as humidification is not required to maintain a reasonable level of comfort in Austin. From the recirculated air heating and cooling data, Figure 4-10, it is apparent that the control strategy should be modified to minimize the simultaneous heating and cooling during the winter months. This would substantially reduce both the heating and cooling loads shown.

Equipment Analysis:

The output requirements again change when the focus of the analysis shifts to the primary equipment. At this point, items such as part load performance and hours of operation at a particular load become important. One difficulty often overlooked in energy management of existing systems is that the efficiency of the primary equipment may be significantly reduced at low load. A centrifugal chiller with hot gas bypass or a large package boiler are examples. If the loads on such equipment are reduced to the point they are operating for significant periods at low efficiency, a major portion of the savings from load reduction may be lost. On the other hand, if the analysis program output provides enough detail to identify this problem, corrective action may be planned..

It is however, essential that these problems be apparent. For example, a summary of monthly or annual energy use resulting from a schedule change or reduced ventilation air would

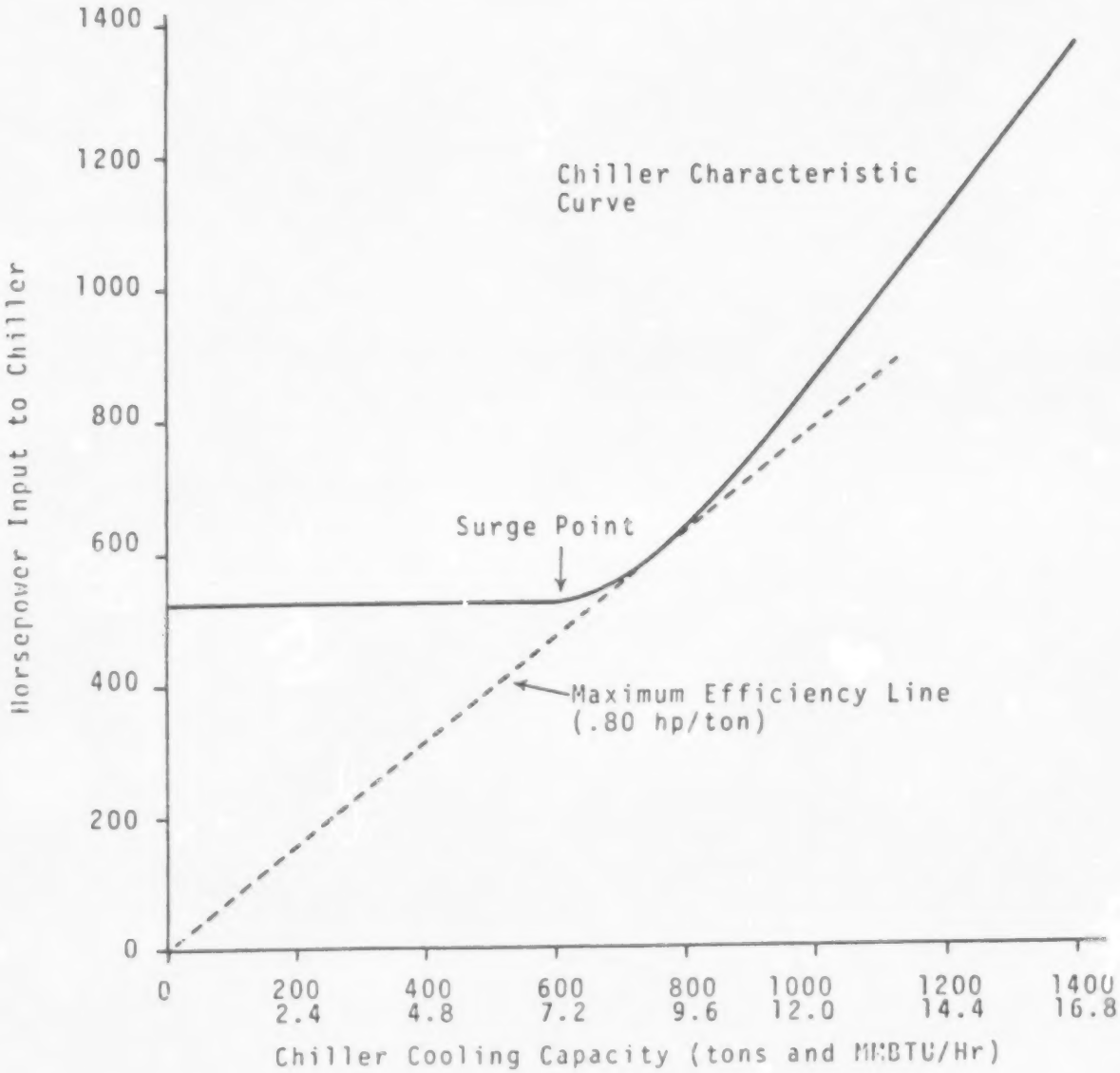
not pinpoint a loss of efficiency at low loads. Thus, if the output is not sufficiently specific, major opportunities for saving may not be recognized. A frequency of occurrence of operating conditions summary for a month or a year is one way to handle this without excessive output. Such features should be carefully considered choosing a program. Figure 4-11 provides such data for the chiller in the State Office building while Figure 4-12 gives the horsepower per ton required as a function of load. The interaction of reduced load and part load performance is such that a 10% reduction in load results in only a 6% reduction in power input. If, however, the problem is recognized and the chiller operation modified at low loads, the power requirements can be reduced by almost matching the reduction in load.

Summary:

The above illustrations are intended to make the following points:

1. Energy analysis programs must be flexible enough to meet a variety of needs - one output format is not suitable for all problems.
2. Too much output may be as much a problem as too little.
3. Computer analysis procedures can not be substituted for an understanding of buildings and HVAC systems. The computer is a very effective tool when used intelligently, but it is only a

FIGURE 4-12: MECHANICAL POWER INPUT REQUIRED TO THE CHILLER TO PRODUCE VARYING AMOUNTS OF COOLING



tool. Thus, it is necessary to plan carefully when establishing an energy analysis program.

When utilized properly computerized analysis wi greatly reduce the time required to solve energy management problems, provide greater insight on building operation and identify and evaluate conservation options. However, if misused, they will provide none of these benefits.

SECTION V

IMPLEMENTING THE PROGRAM

OUTLINE

Introduction

Staff and Training Requirements
- Program Manager
- Computer Systems Analysis
- Data Technician

Procurement and Management

Cost Associated with the Energy Management Program
- "In-House"

Summary

IMPLEMENTING THE PROGRAM

Introduction

A prerequisite for the success of any energy management effort is administrative support. This support may be obtained if administrative personnel

- are informed of what the study team or effort seeks to accomplish;
- are advised of some magnitude of operating cost savings that can be reasonably expected;
- understand that some capital expenditure may be necessary in order to accomplish the recommended changes.

Without management support as outlined above, no energy conservation effort merits either consideration or implementation. Finally, the objective of energy conservation can never be totally realized unless management is willing to enforce reasonable standards as recommended by the study team.

Assuming that administrative support of a conservation effort is available, the next logical questions are:

- what staff and training requirements are necessary for an energy management program;
- what computer capability should be utilized
  - an "in house" capability;
  - a time share capability;
  - or utilization of a computer consultant's program;
- and if an "in house" capability is desirable, how can a computer program be procured, managed, and utilized.

These questions are addressed in the following sections.

Staff and Training Requirements

One staff requirement is that of a program manager. This should be a person who has both a knowledge of air condition systems, how they are modeled

mathematically, and how to write and implement change in the various programs used. His responsibilities include coordinating the computer modeling activities, technical support associated with updating the computer programs, and extracting special data from the computer models. This senior staff member should supervise and coordinate the energy management effort. Involvement of this person in every modeling effort will result in: the proper interpretation of computer results; some guarantee that the modeling effort is realistic relative to what hardware exists and what control schemes can be implemented; and finally, some guarantee that the computer program is indeed modeling what the users think the program is modeling. This person is an engineering manager first and computer programmer second.

The second staff requirement is that of a computer systems analyst (required only if the computer programs are to be run "in house"). This specialist should be extremely knowledgeable about the computer codes in use, various computer languages, and optimal methods of physically manipulating data through various software packages. He must have an intimate and extensive knowledge of the computer being used to run simulation studies.

The third staff requirement is that of a data technician. His primary responsibility is gathering of physical data and inputing it into computer programs. Additional duties include assisting with:

- verification of the operation of a building in accordance with the intended control scheme of the environmental system;
- "bench marking" of the computer results against actual energy consumption, if possible;
- examination of the building's various systems to discover why gross differences exist between the predicted utility consumption and the actual utility consumption;
- determination of what changes to a building or its various systems merit consideration;
- determination of the cost and expected problems associated with each modification;

- determination of "payback" and economic benefits associated with implementing each change;
- the generation of guideline drawings, specifications, and other documentation necessary to accomplish the changes; and finally,
- the "follow-up" necessary to insure that the changes made work properly and produce the expected results.

Gathering of data as input information to a computer program generally entails taking a set of architectural and mechanical plans and taking dimensional and construction data from them. This data is then transcribed onto a coding sheet in a format as required by a particular computer program. It is generally necessary to go into a building and do a room by room survey to ascertain lighting levels, occupancy levels, equipment usage levels, and other pertinent information if the energy study results are to be meaningful. The computer results - relative to actual utilities consumed - improve with greater care and refinement of input data. A recent mechanical engineering graduate with limited background with air conditioning systems could adequately handle this task. The degree of difficulty in gathering data from plans and actual building usage depend on past experience. Some para-professional such as designer-draftsman could also adequately handle this task. Limited success with senior level mechanical engineering college students has been observed. Aside from an intensive one or two day training period (generally helping the person take off one building is sufficient), the training evolves from on the job training. It is desirable that this person be conscientious and reliable in his work.

Staff requirements associated with operation of a building in accordance with the intended control scheme of the environmental system generally require an air and hydraulic balancing technician. This person must know how:

- to take amperage and voltage readings on fan and pump motors;
- to reliably determine the pressure rise across pumps and fans;

- to take velocity traverse data across a duct;
- to measure the discharge from grills, registers, and diffusers; and in addition,
- must have some reasonable understanding of instrument control systems and be able to spot "troublesome" or conflicting air or water balance data in an interpretive way.

No special training for this person is required; his technical competence must pre-exist if he is to be useful. He must be knowledgeable in the use of instruments such as: pitot-static tubes; draft gauges; manometers; deflecting and rotating vane anemometers; a clamp on volt-ammeters; and an Air Monitor or Cambridge Corporation terminal outlet gather hoods. He should know and recognize the importance of recording air and hydronic reporting data forms (such as those produced by the National Environmental Balancing Bureau). This technician contributes in a significant way to "bench marking" the computer results against metered utility data and in resolving the reason or reasons for major variations.

Establishing alternative operating modes for a system and deciding which modifications should be considered as an engineering function of the program manager. Paybacks and economic considerations are also handled by this person.

The generation of design and revision documentation is a engineering function that is outside the scope of the energy management team. This function is best handled by an outside or a separate A/E group with the support and assistance of the energy management team. Evaluation of changes to a building or of changes in one or more of the building's subsystems should be reviewed by the team. This review of system performance would be on the basis of data taken on the revised building systems - especially on a building control system. In all cases data should be recorded and retained as ready reference material for preventative maintenance and evaluating the proper operation of the control system for later review by the team.

Procurement and Management of a Computer Program

The paramount considerations that should be given to acquisition of a computer program are: (1) "Do we really need this (i.e. - could we purchase this service cheaper than we could implement it)?;" (2) "Do we have the computer capability necessary to simulate a building properly?;" (3) "How much effort will be required in 'getting the program up' on my machine?;" and (4) "Where can this type of program capability be acquired?"

Acquisition of and "owning" and operating, in house, a major computer simulation program on the basis of "me too," may and in most instances is, a very poor management decision. Consider the following problems. First, there are computer machine differences. This means that the standard computer program, which is normally written in FORTRAN, generally must be modified when a computer is transported from machine to machine (say CDC to IBM to UNIVAC or even in some cases IBM to IBM). This, in most cases with a major program, is a very time consuming effort that requires someone who knows the peculiarities and characteristics of both computers (i.e., those associated with moving the program from machine A to machine B). This requires both manpower and "unproductive" computer effort, i.e., computer program "debugging." No energy simulation should even be considered until all are satisfied that the computer is correctly doing what is expected of it.

Most people have the misconception that a computer is the ultimate solution to all problems; provides cheap answers; and never requries attention. Hence, this concept is extended to any computer program; and associated with the program is the notion that no changes should ever be required of any program after it is initially implemented. These are false conceptions.

Once a computer program is selected and implemented on a particular machine and useful simulation results are being produced, a good computer

analyst can generally find ways to reduce the computer run time required for simulation. Unfortunately, this requires dedication and extensive knowledge of the program in use on the part of the programmer. Ideally if one judiciously selected the computer program, it would be one that others are also using. Hopefully, the shared knowledge gained through "useage mistakes" as well as any special purpose subroutines that are generated would benefit all. The significance of working with others who are supporting the same computer software should not be taken lightly. Obviously if one has responsibility for only a few buildings, it would be unwise to invest, upward to $25,000, to obtain a program bringing it up "in house," and updating it as required. However, in many instances, groups of users can band together and purchase the same end result at reduced cost to each. Financial maintenance of a computer program at a central location, accessible through the various terminals, by a group of users is perhaps the most desirable way to utilize a computer program in building energy studies. The central computer facility should have either IBM 360-65 (or larger) or CDC 6600 (or larger) machines; most major simulation programs are written to run on these two machines. Conversion of available programs to run on other machines generally can be expected to cost as much as $8,000 in computer time and may require as much as three to six man-months of effort. These estimates obviously vary with the size and complexity of the program; all efforts to determine if other have successfully converted a program to run on a particular machine should be exhausted before conversion is undertaken.

Probably the best load and system simulation program packages that are currently available to the private or public sector are NASA's Energy-Cost Analysis Program (NECAP) or the United States Department of the Army's Construction Engineering Research Laboratory's (CERL) Thermal Loads Analysis

and System Simulation Program. The CERL program is a hybrid program that interfaces the National Bureau of Standards Load Determining (NBSLD) program to the system simulator package of NECAP. These programs (with exception of the CERL) as well as others that are available through the private sector on a fee or useage cost basis are summarized in ASHRAE's Bibliography of Available Computer Programs in the General Area of Heating, Refrigerating, Air Conditioning and Ventilation (funded by the National Science Foundation, NSF-RA-76-00002). Machine requirements, sources as to where to obtain the computer codes and documentation, along with expected cost data are also summarized in this publication. The CERL program, identified above, is no longer being supported; however, interested users should contact Mr. Doug Hittle, USA, CERL, P O Box 4005, Champaign, Illinois 61820.

The latest in the "state of the art" simulation programs that will be released to the general public are Energy Research and Development's CAL-ERDA/1 and CERL's Building Loads Analysis and System Thermodynamics (BLAST) programs. These two programs should supersede all other programs in terms of capability, speed, and ease of use. Unfortunately, they are still in the developmental stages and final completion dates (when the programs will become available to the public) have yet to be determined.

Cost Associated with the Energy Management Program

To implement a computer assisted energy management program, the following staff costs would be required.

- Staff (Minimum Requirements)

Duties	Approximate Annual Cost
* Program Manager	$25,000.00
* Computer Systems Analyst	$18,000.00
* Data Technician	$13,000.00
* Balancing Technician	$15,000.00

These people should be able to audit, simulate, and generate reports on from ten to twenty major buildings per year. Utilization of personnel on a part-time basis would reduce the productivity of the team, accordingly. Additionally, it is assumed that the above personnel are familiar with the computer program they are using (i.e.--they have prior input experience) and that they will utilize an "in house" computer program. (If no "in house" program will be maintained, the job and cost of the computer systems analyst would be omitted).

An "in house" computer capability would require the following:

- Computer Program Acquisition and Operational Cost
  - One Time Cost
    - * Acquisition (Based on NASA's NECAP program - includes documentation) $ 1,500.00
    - * Implement the program "in house" (computer time) $2,000.00 to $20,000.00
    - * Developing initial expertise with the program $2,000.00 to $ 4,000.00
  - Operational Cost (Annual)
    - * Typical major building cost (NECAP) $ 1,500.00
    - * Generation of special purpose subroutines, extracting special simulation results, and continued program development $2,000.00 to $ 4,000.00

It is assumed that the organization that funds and supports the maintenance of the computer capability has a large main frame computer such as an IBM-360, CDC-6600, or a UNIVAC-1100 series machine.

The operation costs associated with simulating a "typical major building" are based on a building divided into 36 zones where two annual space load profiles are run for the building and a total of six energy distribution systems are simulated against the space loads.

The expenses associated with connecting and using a time shared computer

capability vary in accordance with a particular system. Fees charged by speciality computer consultants are subject to negotiations. Accordingly consideration of time shared systems and computer consultant services is beyond the scope of this discussion.

Finally, it should be noted that no reference to "overhead" or other operational costs have been made; these costs would be in addition to those reflected above.

Summary

Before the initiation of an energy management plan, support of the conservation concept by the administration is required. Having secured this support, it must then be established what staff requirements are, as well as what computer capability should be used. Staff requirements for an "in house" capability were established. This team would consist of four members: program manager, systems analyst, data technician and balance technician. Although each team member has several well defined responsibilities, some responsibilities would overlap depending on the particular circumstances and work load of the team.

Computer program procurement decisions should be tempered by considerations associated with expected work load (number of buildings to be simulated), existing computer hardware, program cost and availability, others using the program and whether or not the program is actively being updated. The decision to acquire, implement and maintain an "in house" capability should only be made after careful consideration of all cost and operating factors associated with each alternative.

SECTION VI

UTILIZATION OF CONSULTANTS AND OUTSIDE SERVICES

Outline

Introduction

Overview
- Energy Consumption analysis programs directory

Summary of the energy system analysis series

Presentation Graphics
- Modeling current building systems operation
- Changing key perimeters
- Thermal effects of various changes

Overview of ESA programs

Bibliography

SECTION VI

UTILIZATION OF CONSULTANTS AND OUTSIDE SERVICES

Introduction

Another effective means of using computer assisted energy analysis programs is through a qualified mechanical/electrical engineering consultant or proprietary service. Presently, there are some fifty programs available for computer assisted building energy analysis.

Overview

Computer assisted analysis started during the mid-sixties as a basic research tool to determine the effects of different construction medians in buildings and their effect on energy consumption. Only as a result of the energy crisis has the technique of using a computer been applied to evaluating building design processes and energy conservation for new or existing buildings.

The existing systems have generally resulted from one basic program developed in the mid-sixties which produced the basic mathematical algorithms and fundamental programming. Today, the existing programs suit the needs of various users for specific purposes such as research, building design, and evaluating existing facilities operation. Present energy conservation programs contain two major segments, the energy conservation design tool and the energy consumption analysis program. The energy conservation design tool is used in the early design stages of a new building to develop an energy conserving design, permitting the designer to examine more alternatives in greater detail

than would be possible without computer aids. The energy consumption analysis program deals with the simulation necessary to determine a building's total energy consumption. The reason for using an energy analysis program is to arrive at a value for energy consumption which can be compared with an established energy budget. In both of these programs, specifics such as lighting load, weather conditions, occupancy patterns, building orientation, building design, HVAC systems, and many more considerations are input into the basic program to derive the desired results. A proprietary program is a computer program for building energy analysis which is marketed by a commercial firm. Each program has individual characteristics which make their operation different, depending upon the needs of the person conducting the analysis. Generally, all of the programs are able to provide similar results and calculations to derive energy consumption values, load calculations, and to evaluate alternative design options related to energy conservation programs.

It has been difficult to develop a list which contains all of the computer programs which are useful for energy analysis. Programs have been developed by different organizations, such as the utility companies, national equipment suppliers, research corporations, engineering firms, computer manufacturers, colleges and universities, and the federal government, to name a few. The federal government has been involved in the development of the original Post Office Program, the NASA program, the National Bureau of Standards program called NBSLB, and most recently the CAL/ERDA program.

Physical plant administrators considering using computer programs for building energy analysis are cautioned to evaluate each program fully based on the amount of work load required by physical plant personnel to input data into the program and the expected results of the program selected. Some of the more well known computer programs being marketed by national manufacturing companies are reported to be rather successful and easy to use. However, a number of consulting enginners have found that other programs designed by their counterparts in the engineering field or the utility companies meet their needs in estimating energy consumption for new designs or renovation projects. Computer assisted building energy analysis programming is being accepted widely by consulting engineers throughout the country and being added as a service of these firms. Analysis programs such as this, when effectively used, can assist and permit the physical plant administrator to design or modify a building according to energy conservation design guidelines giving new responsibilities to the administrator and designer. A list of the existing government and proprietary computer programs follows:

ENERGY CONSUMPTION ANALYSIS PROGRAMS DIRECTORY

The following organizations and individuals provided valuable information relating to computer programs applicable to energy conservation. The list does not contain all programs that are useful for energy analysis. The names are presented only for your convenience and should not be assumed to be preferred or warranted by APPA.

American Gas Association
1515 Wilson Boulevard
Arlington, Virginia 22209
Phone: (703) 524-2000
PROGRAM: E CUBE
ATTN: Kenneth T. Cuccinelli

Automated Procedures for Engineering Consultants, Inc.
Grant Deneau Tower
Suite M-15
Dayton, Ohio 45402
Phone: (513) 228-2602
PROGRAM: HCC-III
Lighting II
Piping
Duct
Electrical Feeder - II
SUPER-DUCT
ATTN: Doris Wallace,
Executive Secretary

Beach Engineering Services
75 Manhattan Drive
Boulder, Colorado 80302
Phone: (303) 499-5765
PROGRAM: Solar Collector Performance Analysis
ATTN: Charles D. Beach

CAL/ERDA
Energy Research and Development Administration
Division of Buildings and Industry
Washington, D.C. 20545
Phone: (202) 376-4819
PROGRAM: CAL/ERDA
ATTN: Wilbur T. Coyle,
Program Manager
Architectural and Engineering Systems Branch

University of California, Los Angeles
School of Architecture & Urban Planning
Los Angeles, California 90024
Phone: (213) 825-7370
PROGRAM: CADS; Computer-Aided Design Systems
ATTN: Murray A. Milne,
Associate Dean

Caudill Rowlett Scott
1111 West Loop South
Houston, Texas 77027
Phone: (713) 621-9600
PROGRAM: Energy Analysis

Colorado State University
Mechanical Engineering Department &
Solar Energy Applications Laboratory
Fort Collins, Colorado 80523
Phone: (303) 491-6720 or 491-6783
PROGRAM: Simulation Model for Solar Heated and Cooled Buildings (SIMSHAC)

Consultant Computation Bureau
594 Howard Street
San Francisco, California 94105
Phone: (415) 982-1293
PROGRAM: Post Office Program
ATTN: Zulfikar Cumali

Dalton, Dalton, Little & Newport
3650 Warrensville Center Road
Cleveland, Ohio 44122
Phone: (216) 283-4000
PROGRAM: See Program Lists
ATTN: Willard C. Pistler, Jr.

Dover Corporation
Elevator Division
P.O. Box 2177
Memphis, Tennessee 38101
Phone: (901) 396-6145
PROGRAM: Elevator Design
ATTN: Jack Edwards

Edison Electric Institute
90 Park Avenue
New York, New York 10016
Phone: (212) 573-8700
PROGRAM: AXCESS
ATTN: Edwin S. Douglass

Environmental Research Lab, Inc.
Thunderbird Industrial Air Park
7410 E. Helm Drive
Scottsdale, Arizona 85260
Phone: (602) 948-3471
PROGRAM: Lighting
ATTN: Ian Lewin

University of Florida
Solar Energy Department
237 Mechanical Engineering Building
Gainesville, Florida 32601
Phone: (904) 392-0827
PROGRAM: Energy Program
ATTN: Eric Farber

General American Transportation Corporation
Research Division
7449 N. Natches
Niles, Illinois 60648
Phone: (312) 647-9000
PROGRAM: NECAP
ATTN: Mustafa Akalin

General Electric Company
Lincoln Tower
P.O. Box 1661
Louisville, Kentucky 40210
Phone: (502) 452-3258
PROGRAM: Energy Program
ATTN: Paul F. O'Neil

General Electric Company
P.O. Box 8661
Philadelphia, Pennsylvania 19087
Phone: (215) 962-2784
PROGRAM: Solar Applications
ATTN: W.R. Terrill

Giffels Associates, Inc.
Marquette Building
243 W. Congress
Detroit, Michigan 48226
Phone: (313) 961-2084
PROGRAM: See Program Lists
ATTN: N.N. Pandya

Honeywell, Inc.
1500 West Dundee Road
Arlington Heights, Illinois 60004
Phone: (312) 394-4000
PROGRAM: Energy Program Including the Control System
ATTN: Dr. Gideon Shavit

Honeywell, Inc.
2600 Ridgeway Parkway
Minneapolis, Minnesota 55413
Phone: (612) 331-4141 Ext. 4078
PROGRAM: NBSLD (Honeywell Version)
HELHAK-1; Parabolic Trough Collector
Flat Plate Collector Program
ATTN: R.N. Schmidt, Solar Energy Technical Manager
P. Kruger
J. Hammer

Honeywell, Inc.
Residential Division
2600 Ridgeway Parkway
Minneapolis, Minnesota 55413
Phone: (612) 870-2102
PROGRAM: Residential and Small Commercial Control Simulation
ATTN: John Moberry

IBM
Real Estate and Construction Division
Energy Programs Department
1000 Westchester
White Plains, New York 10604
Phone: (914) 696-1900
PROGRAM: Energy Analysis and Simulation
NBSLD (IBMVERSION)
ATTN: Carlos Garcia Ext. 6555
John Honeycomb, Manager Ext.7857

Johnson Control, Inc.
507 E. Michigan Street
Milwaukee, Wisconsin 53201
Phone: (414) 276-9200
PROGRAM: Control Systems
ATTN: Local Representative

Libbey-Owens-Ford
811 Madison
Toledo, Ohio 43695
Phone: (419) 247-4784
PROGRAM: Glazing Comparison Daylighting Program
ATTN: Jerry Smith

Lokmanhekim Engineering
3026 Fawnwood Drive
Ellicott City, Maryland 21043
Phone: (301) 465-6499
PROGRAM: Advanced Post Office Program
ATTN: Professor Dr. Metin Lokmanhekim

Mechanical Engineering Data Services
30 Kimler Drive
Maryland Heights, Missouri 63043
Phone: (314) 434-2340
PROGRAM: MEDSI Energy Program
ATTN: A.W. Black or Charles J.R. McClure

Ross F. Meriwether & Associates, Inc.
Northwood Executive Building
1600 Northeast Loop 410
San Antonio, Texas 78209
Phone: (512) 824-5302
PROGRAM: Library of Energy Programs
ATTN: Ross F. Meriwether

University of Michigan
College of Architecture & Urban Planning
Ann Arbor, Michigan 48104
Phone: (313) 764-1315
PROGRAM: Energy Program
ATTN: Willard A. Oberdick

NASA
Urban Systems Project Office
Code EZ
Johnson Space Center
Houston, Texas 77058
Phone: (713) 483-5181
PROGRAM: Modified Post Office Program, ESOP
ATTN: Ben Fulbright

National Bureau of Standards
Thermal Engineering Section
Institute for Applied Technology
Washington, D.C. 20234
Phone: (202) 921-3501
PROGRAM: NBSLD
ATTN: Dr. Tamami Kusuda

Otis Elevator Company
260 Eleventh Avenue
New York, New York 10001
Phone: (212) 695-0173
PROGRAM: Elevator Design
ATTN: Local Sales Representative

Pennsylvania State University
Department of Architectural Engineering
University Park, Pennsylvania 16802
Phone: (814) 865-6394
PROGRAM: B.E.A.P.; Building Energy Analysis
ATTN: Edward Hull

Perry, Dean & Stewart
955 Park Square
Boston, Massachusetts 02116
Phone: (617) 482-9160
PROGRAM: ARK-2
ATTN: Kaiman Lee

PPG Industries, Inc.
One Gateway Center
Pittsburgh, Pennsylvania 15222
Phone: (412) 434-3131
PROGRAM: Building Cost/Energy Analysis
ATTN: P.J. McQuillan or Local Representative

Post Office Program
SEE:
Consultants Computation Bureau
General American Corporation
Lokmanhekim Engineering
National Aeronautics and Space Administration

Powers Regulator Co.
3400 Oakton Street
Skokie, Illinois 60076
Phone: (312) 673-6700
PROGRAM: Control Systems
ATTN: Local Representative

Edison Price Inc.
409 East 60th Street
New York, New York 10022
Phone: (212) 838-5212
PROGRAM: Lighting Design
ATTN: Isaac Goodbar

Robertshaw Control Company
P.O. Box 27606
1800 Glenside Drive
Richmond, Virginia 23261
Phone: (804) 338-3081
PROGRAM: Control System
ATTN: Frederic B. Hall, III

Skidmore, Owings and Merrill
30 West Monroe Street
Chicago, Illinois 60603
Phone: (312) 346-6161
PROGRAM: Building Optimization Program (BOP)
ATTN: Charles Davis

Smith, Hinchman & Grylls Associates
455 West Fort Street
Detroit, Michigan 48226
Phone: (313) 964-3000
PROGRAM: Lumen II
ATTN: David L. DiLaura

University of Southern California
Department of Architecture
University Park
Los Angeles, California 90007
Phone: (213) 746-2725
PROGRAM: Thermal Impact Modelling
ATTN: Professor Ralph Knowles

TEC Engineering, Inc.
127 W. 10th Street
Kansas City, Missouri 64105
Phone: (816) 421-7600
PROGRAM: TECON Energy Analysis
HVAC Design Load
Building Orientation
Exterior Shading
System Simulation
Adjustable Thermostat
Mass Heat Release
Economic Analysis
Life Cycle Costing
ATTN: Ray M. Perkins
James R. Smith

University of Texas
Numerical Simulation Laboratory
School of Architecture
Austin, Texas 78712
Phone: (512) 417-1922
PROGRAM: DEROB
SUNNY
DYNAWALB
ATTN: Dr. Francisco Arumi

TRANE Company
3600 Pammel Creek Road
LaCrosse, Wisconsin 54601
Phone: (608) 782-8000
PROGRAM: TRACE: Energy and Economic Analysis, Equipment Selection Programs

Westinghouse Electric Corporation
Building Energy Systems
700 Braddock Avenue
Room 4L39
East Pittsburgh, Pennsylvania 15112
PROGRAM: Load and Energy Program
ATTN: Robert E. Ziegmond (412) 256-2489
Philip L. Frank (412) 256-2608

Westinghouse Electric Company
Box 1693
Baltimore, Maryland 21203
Mail Stop: 999
Phone: (301) 765-2942
PROGRAM: Flat Plate Collector Performance
Solar System Simulation
ATTN: Robert K. Cunningham

University of Wisconsin
Solar Energy Lab
Engineering Research Building
1500 Johnson Drive
Madison, Wisconsin 53706
Phone: (608) 262-1234
PROGRAM: TRNSYS
Attn: John A. Duffie,
TRNSYS Coordinator

WTA Computer Services, Inc.
2357 59th Street
St. Louis, Missouri 63110
Phone: (314) 644-1400
PROGRAM: H.A.C.E.; Heating & Air Conditioning Energy Analysis Program
ATTN: Edward A. Kriege

SUMMARY OF THE ENERGY SYSTEM ANALYSIS SERIES

The Energy System Analysis Series is a library of computer programs developed by Ross F. Meriwether and Associates, Inc. for hour-by-hour calculation of the annual energy consumption of various types of air-side systems and mechanical plants, for applying local utility rate schedules to these demands and consumptions, and for combining these costs with other owning and operating costs for year-by-year cashflow projections. Each major step in a complete energy system analysis is handled by a different program, thereby permitting the engineer to evaluate the results of one part before finalizing inputs and proceeding with the next part. The various programs permit the user to evaluate different air-side system types, various control temperatures, airflow quantities, operating schedules, heat recovery or economizer cycles, various equipment types and accessory combinations, competing energy sources, alternate utility rates, and the impact of various economic factors on total owning and operating costs. The five programs in the library are (see schematic flow diagram on Figure 1):

Energy Requirements Estimate (called ERE) - a program to calculate hour-by-hour thermal and electrical loads for a building (or building section) and to simulate the operation of the air distribution system in meeting these loads.

Total Coincident Requirement (called TCR) - a program to sum the hour-by-hour loads from multiple ERE runs for various buildings or sections to find total system loads with actual diversity.

Equipment Energy Consumption/B (called EEC/B) - a program to simulate the operation of the various pieces of equipment as they respond to loads imposed by the building's air-side systems to find monthly and annual energy consumption for the various systems being evaluated.

Monthly Utility Costs (called MUC) - a program to calculate the monthly and annual energy costs for each system using the local utility rate schedules.

Economic Comparison of Systems/B (called ECS/B) - this program combines typical-year energy costs and other annual operating costs with initial investment and the associated owning cost factors to find the total owning and operating costs of each system year-by-year for any period up to thirty years.

An important distinction exists between design point load programs and energy consumption programs. The Energy System Analysis Series is designed to calculate monthly and annual energy requirements and costs, not design point heating and cooling loads. These programs begin with design point loads for the overall building or major building sections and distribute them throughout a full year cycle of the building's operation. If the engineer is already using a load program, it is usually a simple matter to use the summation of the zone load components from that program as input for the building energy requirements program. These programs are intended to supplement rather than replace existing load programs or calculation techniques. The programs do offer the consulting engineer an excellent means to evaluate and optimize his design by letting him see how his system will respond to varying load and weather conditions.

Hourly weather data that is used in the energy requirements calculations is obtained from the National Climatic Center and consists of 8760 hourly values of dry bulb, dew point, and cloud cover for some typical year. Programs have been developed for selecting and preparing this weather data for use in the Energy System Analysis Series. Since the weather data is usually selected and ordered only once for a given city, Meriwether and Associates normally process the weather data on behalf of the client. If a project is located in a city for which suitable weather data already exists, the client can quickly obtain his own permanent copy of this data at nominal cost.

In addition to hourly weather data for a typical year, the Energy Requirements Estimate program

(ERE) uses solar radiation tables as published in the ASHRAE Handbook of Fundamentals plus the data called for on the input forms. The solar radiation tables are included with the weather data which is supplied to the user. Basically, the ERE program uses the calculated design point heating and cooling loads as a reference and determines the hourly loads using actual values of dry bulb temperature, dew point temperature, cloud cover, solar radiation, and percentage profiles for various building operating schedules. The emphasis and accuracy of this program are primarily devoted to simulating air-side system performance and handling various occupancy and operational schedules, rather than concentrating on the lagging characteristics of transmission loads or the shifting shade patterns associated with solar loads. The intent of the program is to get as close as possible to the overall building energy usage without excessive input detail. The load values which can be included in the heating and cooling calculations are solar; internal, including people, lights, equipment and miscellaneous; transmission; return air plenum solar and transmission loads; supply and return fan loads; and outside air loads. Also, there is a provision for direct and indirect fired process loads such as laboratory equipment, kitchen equipment, domestic hot water, etc., and three contributing sources of base electric load. One of the components of the base electric load can be keyed to come on when a heating or cooling load exists, and in variable volume systems will vary with supply air quantity. Sensible and latent components of the internal load from people and the miscellaneous source are handled separately. There is a provision for a portion of the internal load from lights to pass directly into the return air stream, and a portion of this heat can be designated for reheat purposes in air induction units above the ceiling.

The next step in organizing the input data for ERE is to determine the daily operational schedules of the building and hourly percentages of maximum loads for internal, process, and

base electric. These percentages reflect the move ment of people in and out of the building and the resulting changes in load patterns. The maximum loads and percentage profiles are organized into days of the week, and then months, so that an entire year's operation of the building can be simulated. It is important to recognize that input data should reflect actual anticipated load levels instead of design point values used to size equipment.

The next major step in assembling input data is selecting an air-side system and specifying its control features. Systems that can be simulated are:

1. Single duct, constant volume, variable discharge temperatures set by demand with no excess cooling or reheating.
2. Terminal reheat with scheduled cold coil discharge temperature during the cooling cycle.
3. Terminal reheat with scheduled cold coil discharge temperature during cooling or heating cycles.
4. Induction or fan-coil type system with scheduled primary air temperature.
5. Terminal reheat with cold coil discharge temperature set by maximum demand of any section.
6. Dual-duct with scheduled hot and cold deck temperatures.
7. Dual-duct with deck temperatures set by greatest demand.
8. Split conduit system with single duct, constant volume, variable temperature system to offset transmission loads and a variable volume system for solar and internal.
9. Standard variable volume, scheduled temperature system.
10. Two duct system with cold duct and bypass duct.
11. Combination variable volume dual duct.

Additional features that can be utilized in the ERE program are outside air economizer cycle,

cold deck reset schedules according to ambient temperature or time clock, heat recovery devices operating between return and outside airstreams, supplemental perimeter heating systems that are independent of central system, holiday scheduling for accurate representation of operating schedules, distinction between on and off peak time periods for electrical service, capability to interrupt gas service and switch to auxiliary fuel, calculation of heat storage effects caused by shutoff and setback, and the ability to print selected days during the year to observe the hourly behavior of the system.

The output of the ERE program begins with a display of the input data which can also be obtained by using a data checking feature. This is beneficial to the user since it affords an opportunity to check all the values that will be used in the computer and correct any errors that could cause the ERE program to abort. Percentage variation profiles and operating schedules are shown on an expanded hourly basis for checking and reference. The unitized input data follows and allows the user to compare his input loads to reference "rules-of-thumb". It also permits the user to compare his installed heating and cooling system capacities to the design point loads to verify that the equipment is sized adequately.

The output printout includes monthly and annual peaks and consumptions for heating, cooling, process and base electric loads. The hours of heating and cooling system operation are shown for each month and annually. Data is also given for minimum and maximum room temperature that occurred during the year, number of hours capacities were exceeded, and unitized peak and consumption values for heating, cooling, process and base electric. Two sample pages of printout are shown on Figures 2 and 3.

The input to the Total Coincident Requirement program (TCR) consists of multiple ERE hourly load output tapes plus the data called for on the input forms. A multiplier can be used with each building or section if ERE runs have been made on a unit basis, such as in an apartment complex. The output of the TCR program shows the diversified peaks and time of occurence, as well as the sum of the individual building peaks. The monthly and annual consumptions are shown for the combined plant loads, and unitized values are printed for peaks and consumptions. If desired, a printout is given for the number of hours at ten percent increments of assumed peak loads to aid in equipment sizing. Coincidental peak steam and electrical loads can also be obtained, if desired.

The input to the Equipment Energy Consumption program (EEC/B) consists of an hourly load tape from ERE or TCR plus the data entered on the input forms. The rated capacities and part load performance are required for each piece of equipment, and this equipment is then organized into the various systems and the appropriate accessory equipment loads. Typical systems that can be simulated are total energy with heat recovery, gas heating and cooling, gas heating and electric cooling, all electric, and purchased chilled water and steam or hot water. Energy sources may be gas, electricity, or any other fuel specified by the user. Chillers in each system can be any combination of direct or indirect-fired absorption machines, steam-turbine driven machines, gas engine chillers, or electric motor chillers. Boilers can be gas or electric or any special fuel. Generator sets can be driven by reciprocating gas engines, gas turbines, or steam turbines. Heat recovery can be utilized from prime movers or from chiller condenser water.

Features of this program include: different methods of scheduling machines on the line; various sequencing schedules for accessories; separation of on-peak and off-peak electrical usage for special rates; flexibility in handling recoverable heat and heating requirements in each system; multiple ERE or TCR hourly load tapes representing different sections in a building or different buildings in a complex, permitting separate systems in a single complex to be grouped on a single meter; provision for a multiplier to be used with any system; capability to adjust chiller and generator performance characteristics and their associated accessories for ambient temperature effects; simulation of cooling tower performance with constant or variable condenser water temperature; provision to limit chiller capacity in selected months; provision to limit electrical demand in selected months; and improved methods of handling accessory equipment scheduling. The output information includes monthly and annual peaks and consumptions for energy input to the equipment in each system. Unitized values are also shown for comparison and checking. The number of operating hours is shown for each machine monthly and annually. Full-load operating hours are also shown annually. Other useful information shown in the printout includes utilization of recoverable heat, loads in excess of equipment capacity, and a summary of the energy usage by source. One sample page of printout is shown on Figure 4.

The Monthly Utility Costs program (MUC) uses utility demand and consumption values from a tape generated in the EEC program, plus input cards containing the specific utility rate steps. Alternatively, the demands and consumptions can be entered on cards and the program run independently from any previous program. The MUC program is capable of calculating demand and consumption charges for gas service, electric service, chilled water, steam or hot water, and any special auxiliary fuel. The format for inputting the rate structure data is flexible enough to permit correct handling of almost any rate schedule. The output (Figure 5) shows monthly and

annual costs for each energy form in each system as well as average costs per unit of energy and per square foot. The total yearly energy costs (all forms) are also shown for each system.

The Economic Comparison of Systems program/B (ECS/B) uses the energy costs determined in MUC plus other annual operating costs, such as maintenance and operating labor, and combines these costs with initial investment and associated owning cost factors, such as taxes, insurance, and depreciation, to find the annual cashflow each year for the life of the system. Annual utility costs and other operating costs can be independently escalated each year by a percentage supplied by the user. The initial investment may be divided into two segments with different depreciation periods, and a provision exists for four additional reinvestments (for equipment replacement or staged projects) which can be on a recurring basis. In addition to straight cashflow and a discounted cashflow for each system on an independent basis, a comparison can be made of each system to the lowest first cost system to show the net savings of reduced operating costs compared to higher owning costs.

The output for each system (Figure 6) shows the year-by-year and total period values of debt balance, debt interest, equity balance, equity interest, book or tax depreciation, insurance, ad volorem tax, total owning cost, total operating cost, total owning plus operating cost, and equivalent current dollars. If a comparative analysis is performed, the printout (Figure 7) shows annual and total values of owning and operating costs savings, total owning and operating cost savings before tax, principal payment difference, depreciation difference, taxable income, total owning and operating cost savings after tax, and discounted cashflow after tax. The discounted rate of return on total gross investment difference and the number of years to recover initial gross investment difference are also shown.

The schedule of fees for the use of each of the programs in the library is shown after the sample printout.

THE ENERGY SYSTEM ANALYSIS SERIES

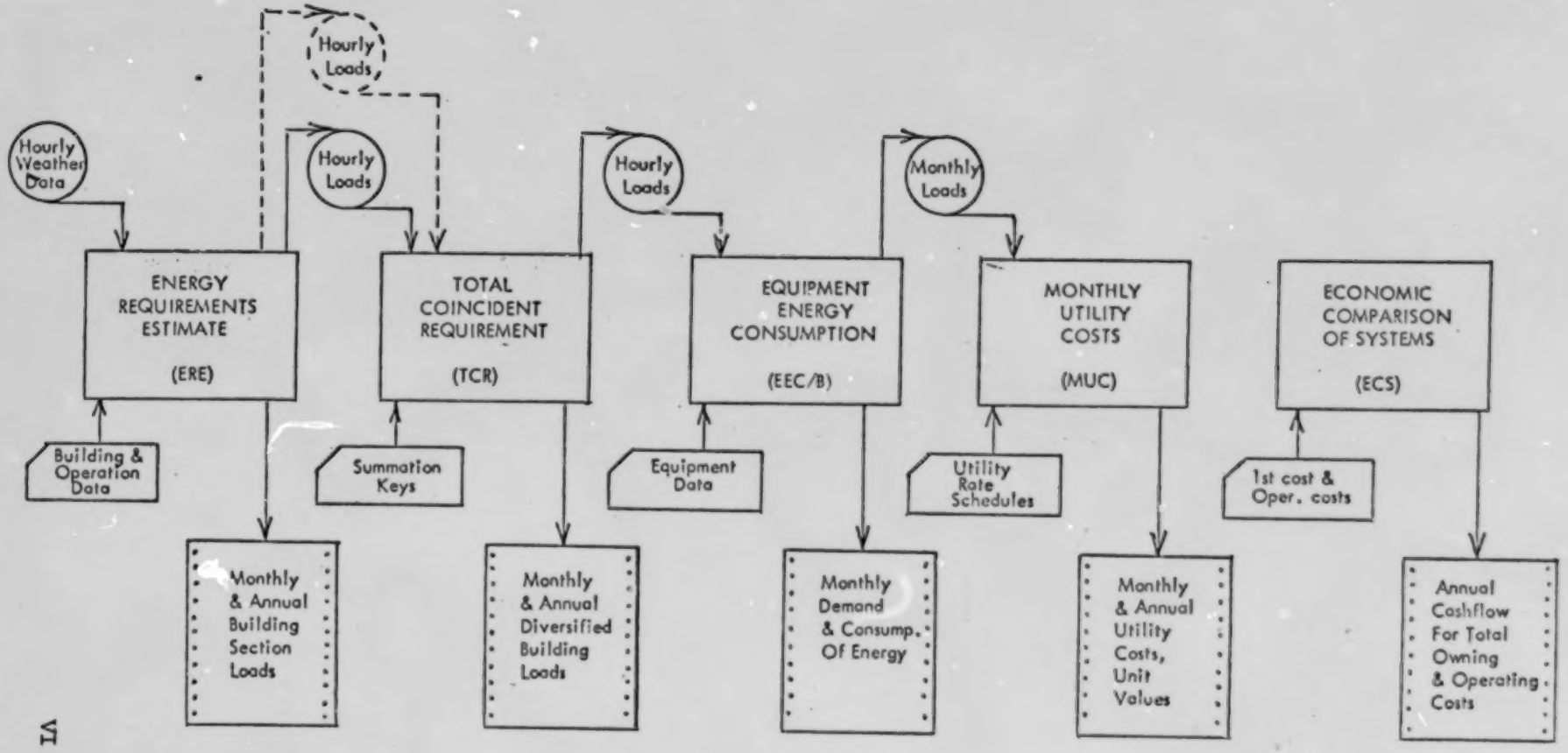

Hourly Loads
Hourly Weather Data
Hourly Loads
Hourly Loads
Monthly Loads
ENERGY REQUIREMENTS ESTIMATE (ERE)
TOTAL COINCIDENT REQUIREMENT (TCR)
EQUIPMENT ENERGY CONSUMPTION (EEC/B)
MONTHLY UTILITY COSTS (MUC)
ECONOMIC COMPARISON OF SYSTEMS (ECS)
Building & Operation Data
Summation Keys
Equipment Data
Utility Rate Schedules
1st cost & Oper. costs
Monthly & Annual Building Section Loads
Monthly & Annual Diversified Building Loads
Monthly Demand & Consump. Of Energy
Monthly & Annual Utility Costs, Unit Values
Annual Cashflow For Total Owning & Operating Costs

FIGURE 1

ENERGY REQUIREMENT ESTIMATE PROGRAM FOR

SAMPLE OUTPUT

MONTHLY AND ANNUAL LOADS

	HEATING MBTU	HEAT HOURS	COOLING TON-HRS	COOL HOURS	HUMIDFCN MBTU	IND PROC MBTU	DIR PROC MBTU	BS ELEC A KWH	BS ELEC B KWH	BS ELEC C KWH	TOT BS EL KWH	AUX F HRS
JAN	57411.	744	250.	37	0.	384473.	0.	23806.	22490.	78120.	124397.	0
FEB	480417.	672	271.	35	0.	347271.	0.	21502.	20414.	70560.	112461.	0
MAR	446375.	744	1533.	121	0.	384473.	0.	23806.	22970.	78120.	124876.	0
APR	275012.	720	5340.	357	0.	372072.	0.	23038.	22198.	75600.	120818.	0
MAY	221855.	744	20618.	640	0.	384473.	0.	23806.	22730.	78120.	124637.	0
JUN	102440.	720	42293.	713	0.	372072.	0.	23038.	22198.	75600.	120818.	0
JUL	20[illegible]83.	744	53966.	744	0.	384473.	0.	23806.	22730.	78120.	124636.	0
AUG	20[illegible]73.	744	46[illegible]7.	744	0.	384473.	0.	23806.	22970.	78120.	124876.	0
SEP	212512.	720	28106.	668	0.	372072.	0.	23038.	22198.	75600.	120818.	0
OCT	2[illegible]715.	744	10255.	452	0.	384473.	0.	23806.	22730.	78120.	124637.	0
NOV	33[illegible]3.	720	2625.	163	0.	372072.	0.	23038.	21958.	75600.	120578.	0
DEC	2[illegible]5.	744	140.	22	0.	384473.	0.	23806.	22970.	78120.	124876.	0
ANN	4[illegible]0.	8760	213702.	4696	0.	4526964.	0.	280291.	268559.	919800.	1468426.	0

FIGURE 2

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123

ENERGY REQUIREMENT ESTIMATE PROGRAM FOR

SAMPLE OUTPUT

	SO OR SH	MO/DY/TIME	NORM OPER	MO/DY/TIME
MIN ROOM TEMP	74.64 F	1/23/ 8AM	75.00 F	0/ 0/
MAX ROOM TEMP	75.00 F	0/ 0/	75.00 F	0/ 0/
MAX ROOM HUMIDITY RATIO	65.38 GR	4/12/ 5PM		

BASIC HEATING LOAD 303e2e5. MBTU

BASIC COOLING LOAD 11e8e1. TON-HRS

COUNT OF HOURS ON LIMITING CONDITIONS	HEATING	COOLING
SPACE LOAD NOT MET (INCL PICKUP LOAD)	65	0
SPACE LOAD NOT MET (W/O PICKUP LOAD)	59	0
SYSTEM CAPACITY EXCEEDED	65	0
LONGEST PICKUP PERIOD	11	0
LAST HOUR OF OCCURRENCE	1/23/11AM	0/ 0/

UNIT VALUES OF BUILDING ENERGY PEAKS AND CONSUMPTION

HEATING PEAK	43.60	BTUH/SQFT
HEATING CONSUMPTION	154.66	MBTU/SQFT
FULL LOAD HEATING	3547.	HRS
COOLING PEAK	5.25	TONS/1000 SQFT
OR	190.37	SQFT/TON
COOLING CONSUMPTION	8.19	TON-HRS/SQFT
FULL LOAD COOLING	1559.	HRS
PROCESS PEAK	31.72	BTUH/SQFT
PROCESS CONSUMPTION	173.44	MBTU/SQFT
INDIRECT	173.44	MBTU/SQFT
DIRECT	0.0	MBTU/SQFT
FULL LOAD PROCESS	5467.	HRS
ELECTRIC PEAK	8.74	WATTS/SQFT
ELECTRIC CONSUMPTION	56.26	KWH/SQFT
FULL LOAD ELECTRIC	6440.	HRS

PEAK HEATING LOAD DURING SETBACK 0. MBH

FIGURE 3

EQUIPMENT ENERGY CONSUMPTION AND OPERATING DATA FOR

A TYPICAL OFFICE BUILDING 7/13/70

SYS	MO	GAS DEMAND MCF	GAS CONSUMP MCF	ELEC DEMAND KW	ELEC CONSUMP KWH	AUX FUEL CONSUMP	AUX FUEL HRS	COOLING DEMAND TONS	COOLING CONSUMP TON-HRS	HEAT DEMAND MBH	HEAT CONSUMP MBTU
1	1	938	19057	0	0	0	0	1886	82256	21709	5796989
1	2	905	17940	0	0	0	0	1840	152670	21709	4092032
1	3	986	21603	0	0	0	0	2104	368463	20977	1627552
1	4	1115	22476	0	0	0	0	2987	413012	21589	1397371
1	5	1182	25578	0	0	0	0	3010	569388	19938	205998
1	6	1221	25370	0	0	0	0	3010	580849	10911	79541
1	7	1248	27683	0	0	0	0	3010	647101	465	73839
1	8	1236	27654	0	0	0	0	3010	643905	11465	95363
1	9	1293	24406	0	0	0	0	3010	544102	19043	183477
1	10	1065	24402	0	0	0	0	2872	483797	20504	1088853
1	11	1009	19160	0	0	0	0	2112	188443	21709	3896276
1	12	941	19405	0	0	0	0	1927	158551	21709	4507951
2	1	631	10312	5227	1623882	0	0	1886	82256	21709	5796989
2	2	596	10046	5227	1490899	0	0	1840	152670	21709	4092032
2	3	677	12942	5350	1630536	0	0	2104	368463	20977	1627552
2	4	804	13922	5350	1649134	0	0	2987	413012	21589	1397371
2	5	871	16819	5350	1684253	0	0	3010	569388	19938	205998
2	6	908	16977	5350	1593910	0	0	3010	580849	10911	79541
2	7	935	18891	5350	1695394	0	0	3010	647101	465	73839
2	8	923	18835	5350	1711887	0	0	3010	643905	11465	95363
2	9	979	16051	5350	1572569	0	0	3010	544102	19043	183477
2	10	754	15563	5350	1719545	0	0	2872	483797	20504	1088853
2	11	700	10858	5350	1548945	0	0	2112	188443	21709	3896276
2	12	634	10797	5227	1590379	0	0	1927	158551	21709	4507951
3	1	414	7871	6664	1672167	0	0	1886	82256	21709	5796989
3	2	411	5560	6682	1589493	0	0	1840	152670	21709	4092032
3	3	295	2224	6894	1880494	0	0	2104	368463	20977	1627552
3	4	194	1912	6945	1929295	0	0	2987	413012	21589	1397371
3	5	51	298	7183	2072528	0	0	3010	569388	19938	205998
3	6	17	126	7279	1988390	0	0	3010	580849	10911	79541
3	7	5	119	7370	2135885	0	0	3010	647101	465	73839
3	8	30	149	7305	2149705	0	0	3010	643905	11465	95363
3	9	53	266	7554	1942503	0	0	3010	544102	19043	183477
3	10	188	1495	7033	2050637	0	0	2872	483797	20504	1088853
3	11	389	5296	6903	1674050	0	0	2112	188443	21709	3896276
3	12	411	6125	6770	1693340	0	0	1927	158551	21709	4507951
4	1	0	0	10649	3367768	0	0	1886	82256	21709	5796989
4	2	0	0	10638	2785802	0	0	1840	152670	21709	4092032
4	3	0	0	10672	2354899	0	0	2104	368463	20977	1627552
4	4	0	0	10580	2336401	0	0	2987	413012	21589	1397371
4	5	0	0	9028	2131300	0	0	3010	569388	19938	205998
4	6	0	0	7351	2010403	0	0	3010	580849	10911	79541
4	7	0	0	7441	2156151	0	0	3010	647101	465	73839
4	8	0	0	7376	2176201	0	0	3010	643905	11465	95363
4	9	0	0	8969	1994811	0	0	3010	544102	19043	183477
4	10	0	0	10677	2367523	0	0	2872	483797	20504	1088853
4	11	0	0	10666	2813016	0	0	2112	188443	21709	3896276
4	12	0	0	10676	3011437	0	0	1927	158551	21709	4507951

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FIG 4

MONTHLY AND ANNUAL UTILITY COST FOR

A TYPICAL OFFICE BUILDING 7/13/70

	ELECTRIC COST, $	AVER RATE C/KWH	UNIT COST C/SQFT	GAS COST, $	AVER RATE C/MCF	UNIT COST C/SQFT	AUX FUEL COST, $	AVER RATE C/UNIT	UNIT COST C/SQFT	CHILLED WATER COST, $	AVER RATE C/TNHR	UNIT COST C/SQFT	STEAM OR HOT WATER COST, $	AVER RATE $/MMB	UNIT COST C/SQFT
SYSTEM 3 GAS HEAT, ELEC COOL															
JAN	20714	1.239	2.589	2950	37.48	.369									
FEB	20157	1.268	2.520	2107	37.89	.263									
MAR	22469	1.195	2.809	890	40.00	.111									
APR	22877	1.186	2.860	776	40.58	.097									
MAY	24185	1.167	3.023	168	56.44	.021									
JUN	23717	1.193	2.965	101	79.79	.013									
JUL	24868	1.164	3.109	97	81.79	.012									
AUG	24883	1.157	3.110	111	74.56	.014									
SEP	23745	1.222	2.968	157	59.09	.020									
OCT	23841	1.163	2.980	565	37.76	.071									
NOV	21032	1.256	2.629	2011	37.96	.251									
DEC	20998	1.240	2.625	2313	37.76	.289									
ANN	273486	1.201	34.186	12245	38.95	1.531									
SYSTEM 4 ALL ELECTRIC															
JAN	37693	1.119	4.712												
FEB	33594	1.206	4.199												
MAR	30613	1.300	3.827												
APR	30366	1.300	3.796												
MAY	26949	1.264	3.369												
JUN	23963	1.192	2.995												
JUL	25101	1.164	3.138												
AUG	25159	1.156	3.145												
SEP	25916	1.299	3.239												
OCT	30708	1.297	3.838												
NOV	33821	1.202	4.228												
DEC	35226	1.170	4.403												
ANN	359110	1.217	44.889												
SYSTEM 5 PURCHASED STEAM + CH WTR															
JAN	17103	1.135	2.138	29	151.16	.004	0	0.00	0.000	12933	15.72	1.617	10748	2.15	1.344
FEB	16152	1.177	2.019	27	151.16	.003	0	0.00	0.000	14341	9.39	1.793	9528	2.70	1.191
MAR	16895	1.143	2.112	29	151.16	.004	0	0.00	0.000	18361	4.98	2.295	5209	3.71	.651
APR	16985	1.140	2.123	29	151.16	.004	0	0.00	0.000	22788	5.52	2.848	4614	3.83	.577
MAY	17103	1.135	2.138	29	151.16	.004	0	0.00	0.000	25466	4.47	3.183	710	4.00	.089
JUN	16479	1.162	2.060	29	151.16	.004	0	0.00	0.000	25638	4.41	3.205	274	4.00	.034
JUL	17103	1.135	2.138	29	151.16	.004	0	0.00	0.000	26632	4.12	3.329	255	4.00	.032
AUG	17193	1.131	2.149	30	151.16	.004	0	0.00	0.000	26584	4.13	3.323	329	4.00	.041
SEP	16390	1.166	2.049	27	151.16	.003	0	0.00	0.000	25087	4.61	3.136	633	4.00	.079
OCT	17401	1.123	2.175	30	151.16	.004	0	0.00	0.000	23451	4.85	2.931	3755	4.00	.469
NOV	16479	1.162	2.060	29	151.16	.004	0	0.00	0.000	15056	7.99	1.882	9359	2.79	1.170
DEC	16806	1.147	2.101	29	151.16	.004	0	0.00	0.000	14459	9.12	1.807	9886	2.54	1.236
ANN	202089	1.146	25.261	345	151.16	.043	0	0.00	0.000	250793	5.19	31.349	55299	2.78	6.912

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FIGURE 5

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ECONOMIC COMPARISON OF SYSTEMS FOR A TYPICAL OFFICE BUILDING 7/13/70

DATA FOR SYSTEM 3 CONVENTIONAL WITH GAS HEATING AND ELECTRIC COOLING

GROSS INVESTMENT, $ 2368000
MONTHLY PAYMT, $ 21306
1ST REINVESTMENT, $ 0 YRS 0,
2ND REINVESTMENT, $ 0 YRS 0,

DEBT/EQUITY RATIO 100.0/ 0.0

END OF YEAR	DEBT BALANCE *	DEBT INTEREST (9.0 PCT)	EQUITY BALANCE	EQUITY INTEREST (0.0 PCT)	BOOK DEPRC (SL 40TH)	INSURANCE (.9 PCT)	AD VALOREM TAX (1.5 PCT)	TOTAL OWN COST*	TOTAL OPR COST	TOTAL OWN + OPR COST	EQUIV CURR DOLLARS (7.0 PCT)
1	2323654	211320	0	0	94720	21312	35520	312498	315731	628229	587130
2	2275148	207160	0	0	94720	21312	34099	311077	318400	629477	549810
3	2222093	202610	0	0	94720	21312	32678	309657	321109	630766	514893
4	2164060	197633	0	0	94720	21312	31258	308236	323860	632096	482223
5	2100583	192189	0	0	94720	21312	29837	306815	326654	633469	451654
6	2031152	186235	0	0	94720	21312	28416	305394	329491	634885	423051
7	1955207	179722	0	0	94720	21312	26995	303973	332373	636346	396284
8	1872138	172598	0	0	94720	21312	25574	302553	335301	637854	371237
9	1781277	164805	0	0	94720	21312	24154	301132	338277	639408	347796
10	1681893	156282	0	0	94720	21312	22733	299711	341301	641011	325858
11	1573186	146959	0	0	94720	21312	21312	298290	344374	642665	305325
12	1454281	136761	0	0	94720	21312	19891	296869	347500	644369	286107
13	1324222	125607	0	0	94720	21312	18470	295449	350677	646126	268119
14	1181963	113407	0	0	94720	21312	17050	294028	353909	647937	251281
15	1026358	100062	0	0	94720	21312	15629	292607	357196	649803	235519
16	856157	85465	0	0	94720	21312	14208	291186	360541	651727	220762
17	669990	69499	0	0	94720	21312	12787	289765	363944	653709	206948
18	466359	52035	0	0	94720	21312	11366	288345	367407	655752	194013
19	243627	32933	0	0	94720	21312	9946	286924	370932	657856	181903
20	0	12039	0	0	94720	21312	8525	285503	374521	660024	170563
21	0	0	0	0	94720	21312	7104	28416	378176	406592	98197
22	0	0	0	0	94720	21312	5683	26995	381898	408893	92293
23	0	0	0	0	94720	21312	4262	25574	385689	411263	86755
24	0	0	0	0	94720	21312	2842	24154	389551	413705	81561
25	0	0	0	0	94720	21312	1421	22733	393487	416220	76688
TOTAL		2745323		0	2368000	532800	461760	6107883	8802298	14910181	7205969

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* INCLUDES PRINCIPAL REPAYMENT (IF APPLICABLE)

FIGURE 6

ECONOMIC COMPARISON OF SYSTEMS FOR A TYPICAL OFFICE BUILDING 7/13/70

SYSTEM 3 CONVENTIONAL WITH GAS HEATING AND ELECTRIC COOLING
VS
SYSTEM 5 PURCHASED STEAM AND CHILLED WATER

TOTAL GROSS INVESTMENT DIFFERENCE $ 683000
DISCOUNTED GROSS INVEST DIFF (7.0 PCT) $ 683000

END OF YEAR	OWNING COST SAVINGS*	OPERATING COST SAVINGS	BEFORE TAX TOT OWN + OPR COST SAVINGS	PRINCIPAL PAYMENT DIFFERENCE	DEPREC DIFFERENCE	TAXABLE INCOME	AFTER TAX TOT OWN + OPR COST SAVINGS	AFTER TAX DISCOUNTED CASHFLOW** (7.0 PCT)
1	--90134	202295	112161	12791	40980	83972	71855	79108
2	-89724	204220	114496	13990	38521	89965	71313	74507
3	-89314	206153	116839	15303	36210	95932	70792	70279
4	-88904	208094	119190	16738	34037	101891	70282	66387
5	-88494	210042	121548	18309	31995	107861	69774	62802
6	-88085	211997	123913	20026	30075	113864	69258	59494
7	-87675	213960	126285	21905	28271	119919	68724	56439
8	-87265	215928	128663	23959	26575	126048	68160	53614
9	-86855	217902	131047	26207	24980	132274	67556	51001
10	-86445	219882	133437	28665	24460	137643	67369	48819
11	-86036	221867	135832	31354	24460	142726	67323	46841
12	-85626	223856	138231	34296	24460	148067	67159	45047
13	-85216	225850	140634	37513	24460	153687	66864	43313
14	-84806	227846	143040	41032	24460	159612	66426	41674
15	-84396	229846	145450	44881	24460	165871	65832	40127
16	-83987	231848	147861	49091	24460	172492	65065	38669
17	-83577	233851	150275	53696	24460	179511	64109	37294
18	-83167	235856	152689	58733	24460	186962	62947	36001
19	-82757	237861	155103	64243	24460	194886	61558	34785
20	-82347	239865	157518	70269	24460	203327	59921	33644
21	-8196	241868	233672	0	24460	209213	133250	32182
22	-7786	243870	236084	0	24460	211624	134504	30359
23	-7376	245869	238492	0	24460	214033	135757	28637
24	-6967	247864	240897	0	24460	216438	137007	27011
25	-6557	249855	243298	0	24460	218838	138256	25474
TOTAL	-1761691	5648345	3886654	683000	683000	3886654	2021060	1163546

DISCOUNTED RATE OF RETURN ON TOTAL GROSS INVESTMENT DIFFERENCE 13.2 PERCENT

YEARS TO RECOVER INITIAL GROSS INVESTMENT DIFFERENCE 7.8

* LOAN REPAYMENT DIFFERENCE DEDUCTED (IF APPLICABLE)
** PRINCIPAL PORTION OF LOAN REPAYMENT DIFFERENCE ADDED (IF APPLICABLE)

FIGURE 7

SECTION VI

PRESENTATION GRAPHICS

Computer Analysis of Energy Use
in Existing Buildings

1. Identifying the "dogs"
2. Modeling buildings and systems as now operated
3. Changing operating and design perimeters

OFFICE BLDGS IN NEW YORK

86 BLDG SAMPLE

ENERGY CONSUMPTION / S.F. / YR

	HIGH	LOW	AVG
ALL ENERGY, MBTU	403	72	211
STEAM, MBTU	299	51	141
ELEC, KWH	45	11	20

Comparison of 6 Virginia High Schools
1971-72

School	Yr Built	Gross Area	Heating ¢/GSF	Cooling ¢/GSF	Energy ¢/GSF	%over MIN
A	65	290M	6.1	7.4	13.5	8.9
B	64	214M	4.6	10.9	15.5	25.0
C	66	289M	4.3	8.1	12.4	-0-
D	66	279M	5.3	11.4	16.8	35.5
E	67	461M	3.4	10.6	14.0	12.9
F	69	491M	6.3	17.1	23.4	88.7

Energy Cost Changes by Year

Virginia High Schools

	Electric Costs, $			Oil Costs, $		
	70-71	71-72	% CHG	70-71	71-72	% CHG
D	28,719	31,912	+11.1	14,776	14,917	+1.0
E	59,080	48,817	-17.4	17,258	15,463	-10.4

EFFECT OF INPUT ERRORS

VIRGINIA HIGH SCHOOL

	ORIGINAL ASSUMPT	AFTER FIELD CORR	% ERROR IN ORIG
HEATING, MMBTU	6,817	5,898	+15.6
COOLING, MTH	144	308	-53.2
BASE ELEC, MKWH	1,344	2,720	-50.6

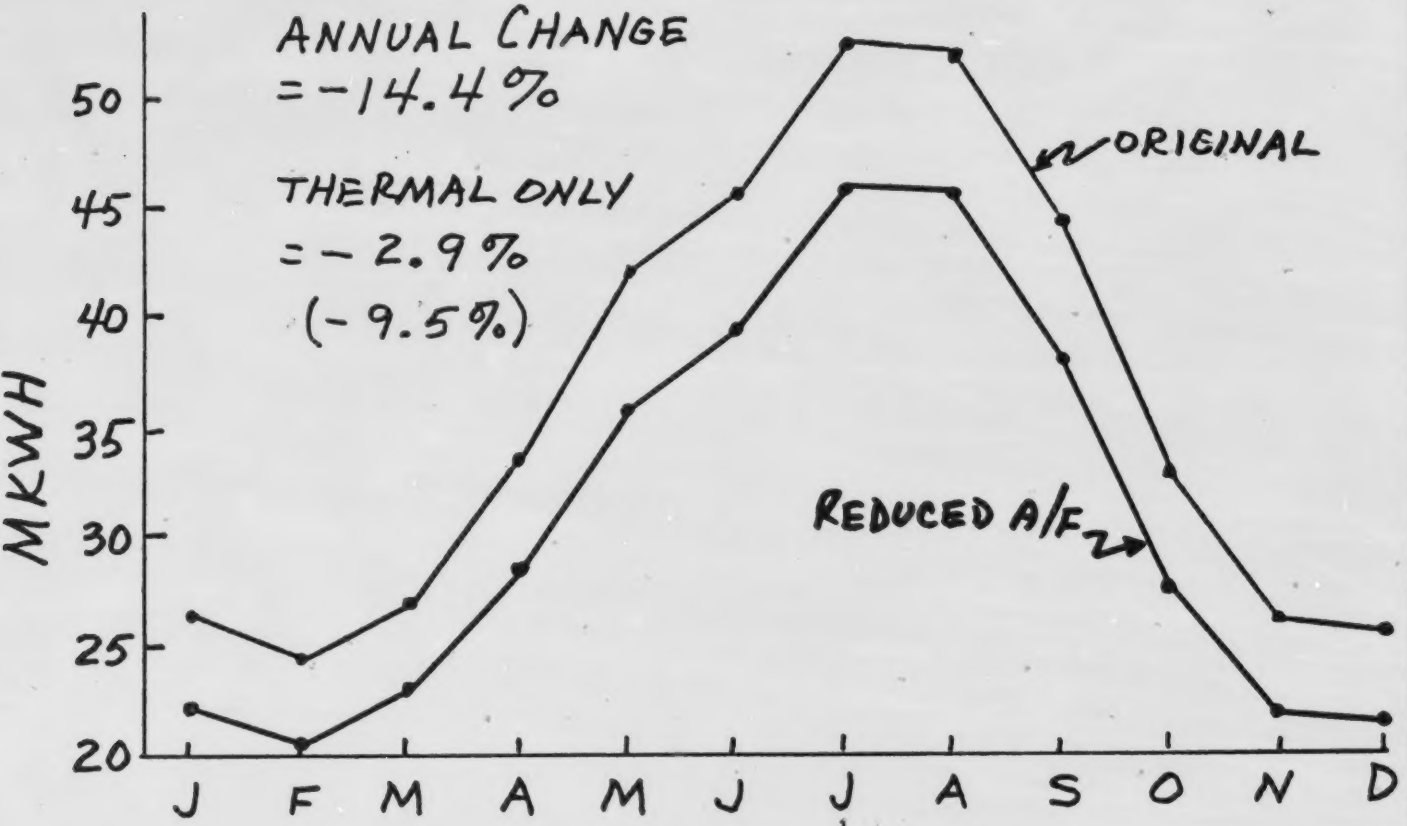
MODELING CURRENT BLDG/SYS OPERATION

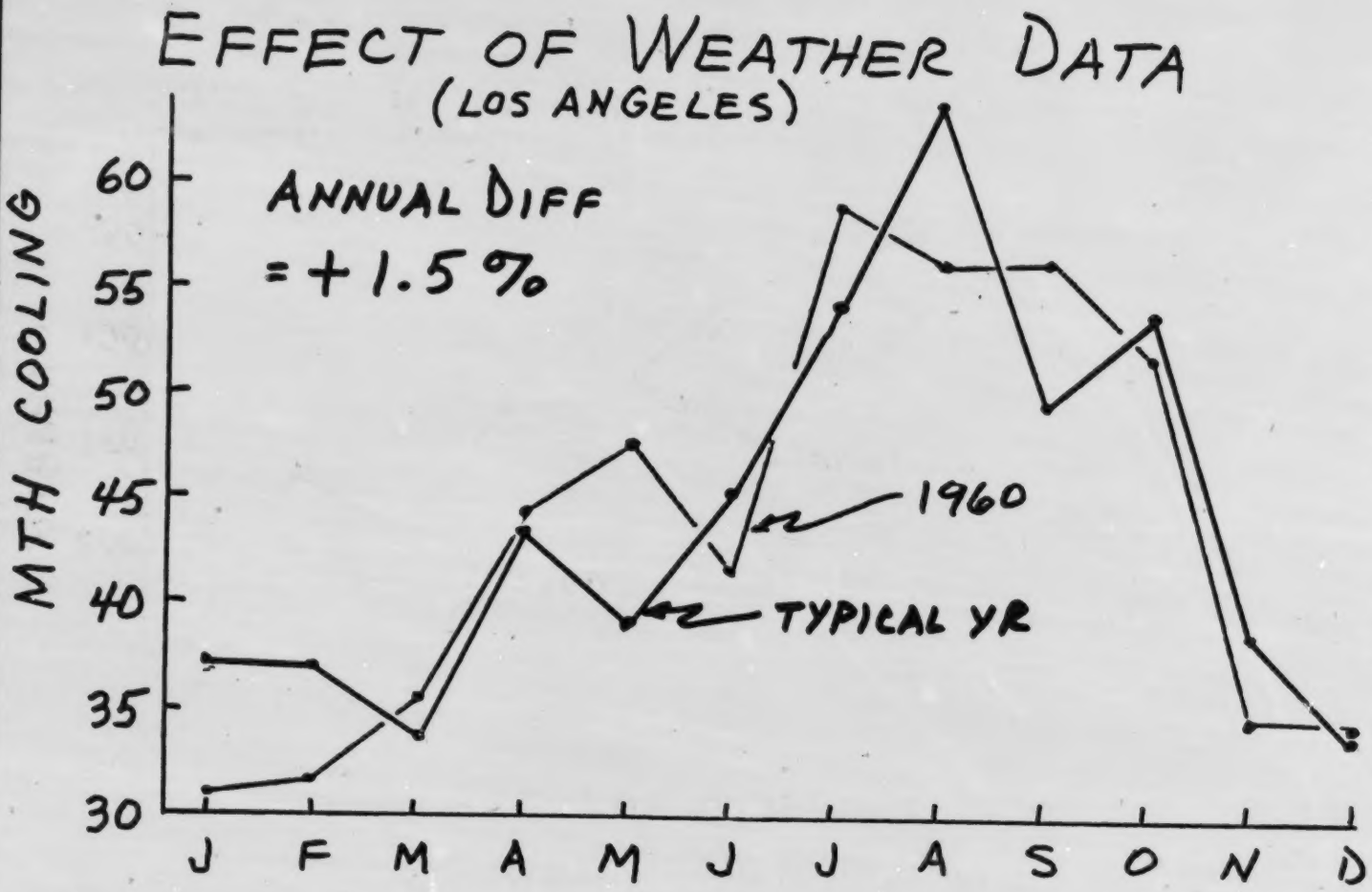
1. START WITH ORIGINAL DESIGN AND ASSUMED PRESENT OPERATION

2. VERIFY BY FIELD OBSERVATION AND MEASUREMENT

3. JUGGLE UNKNOWN INPUTS TO GET REASONABLE TRACK WITH EXISTING UTILITY BILLS

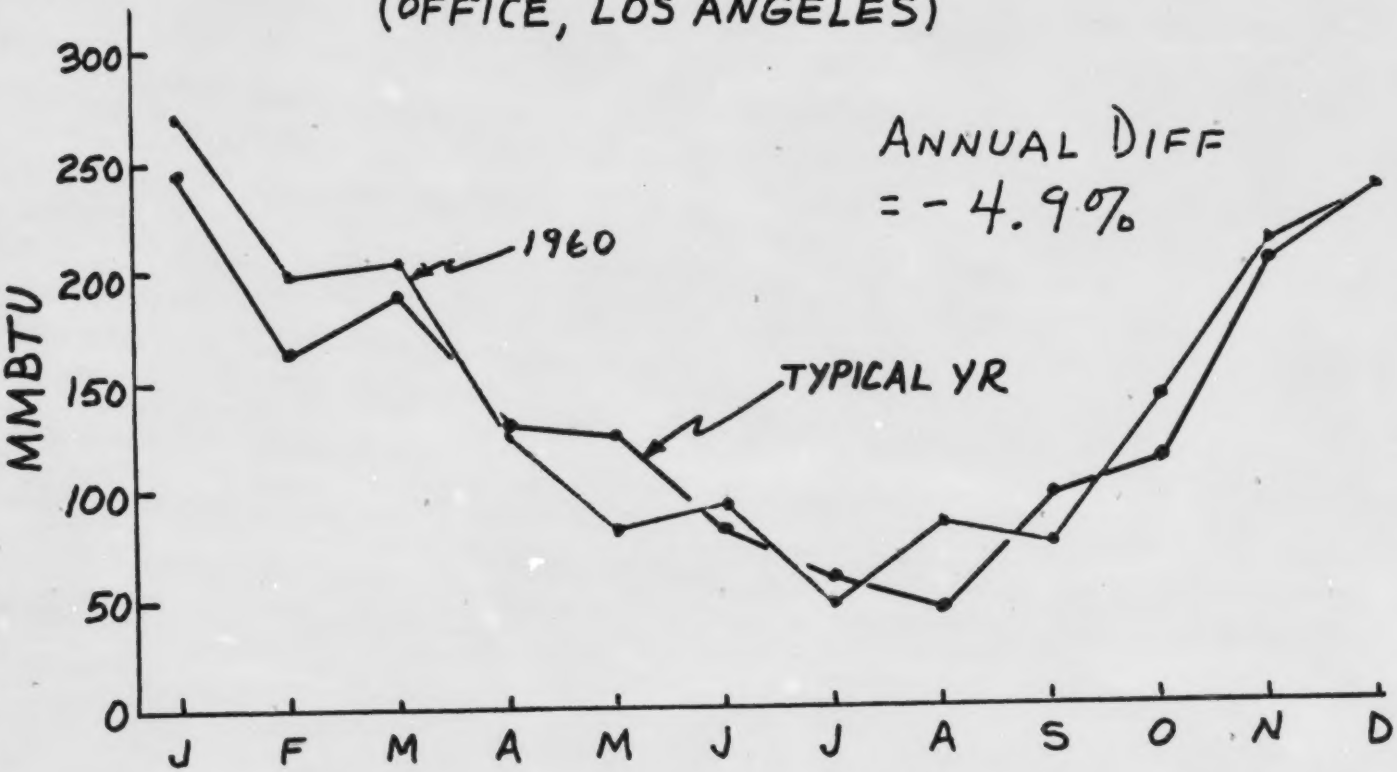
EFFECT OF REDUCING AIRFLOW 15%



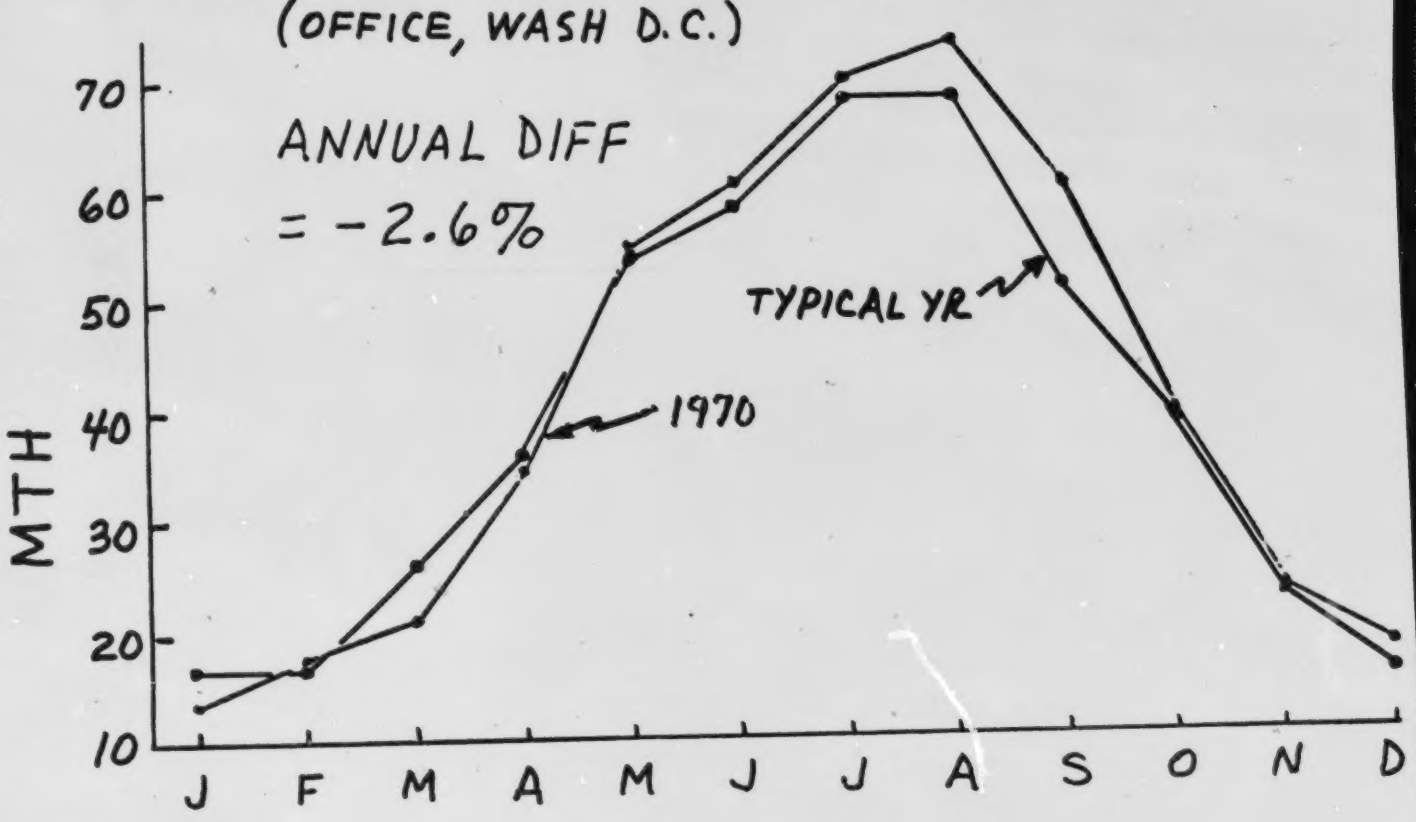

EFFECT OF WEATHER DATA
(LOS ANGELES)
ANNUAL DIFF
= +1.5%
MTH COOLING
60
55
50
45
40
35
30
1960
TYPICAL YR
J
F
M
A
M
J
J
A
S
O
N
D

EFFECT OF WEATHER ON HEATING

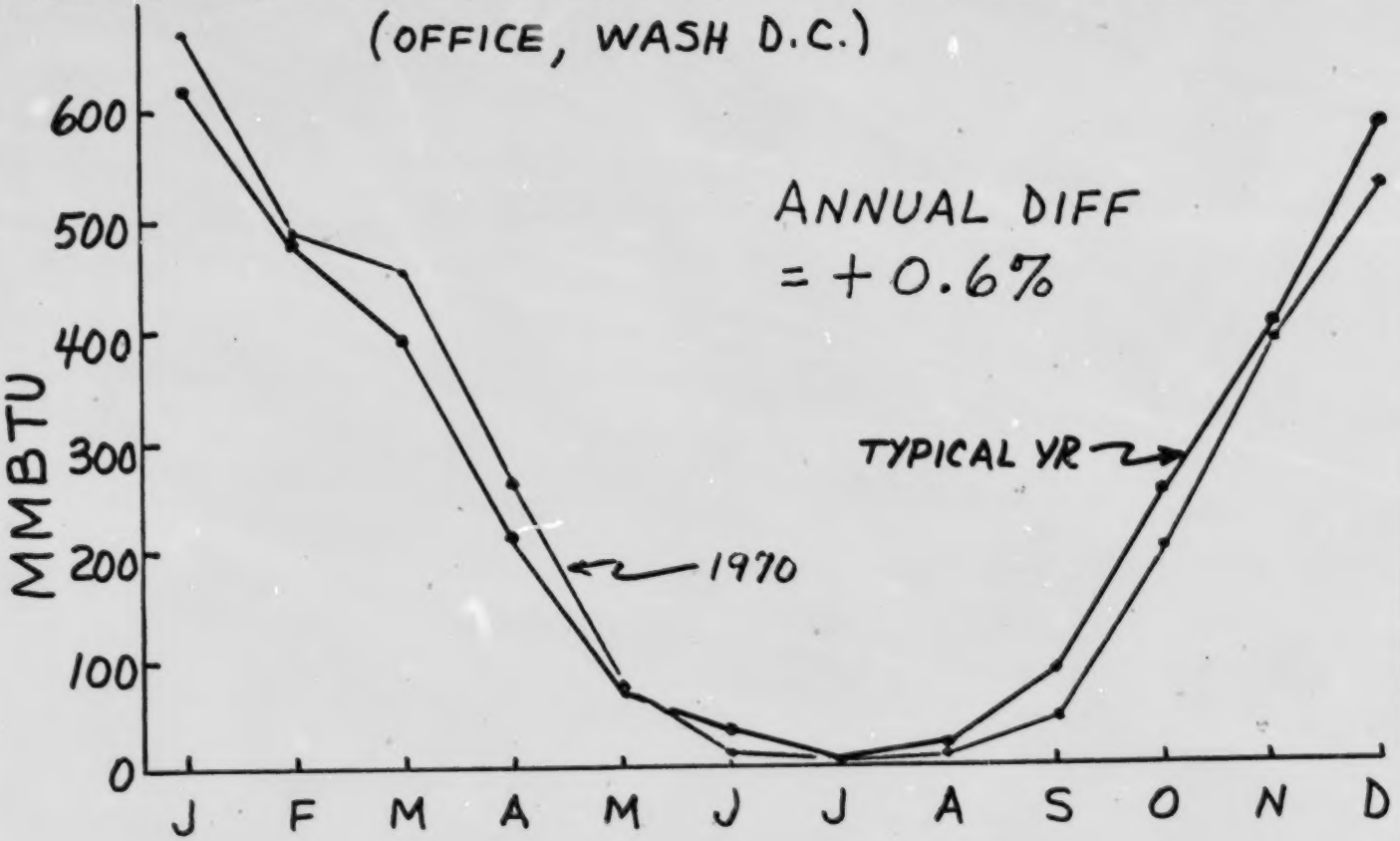
(OFFICE, LOS ANGELES)



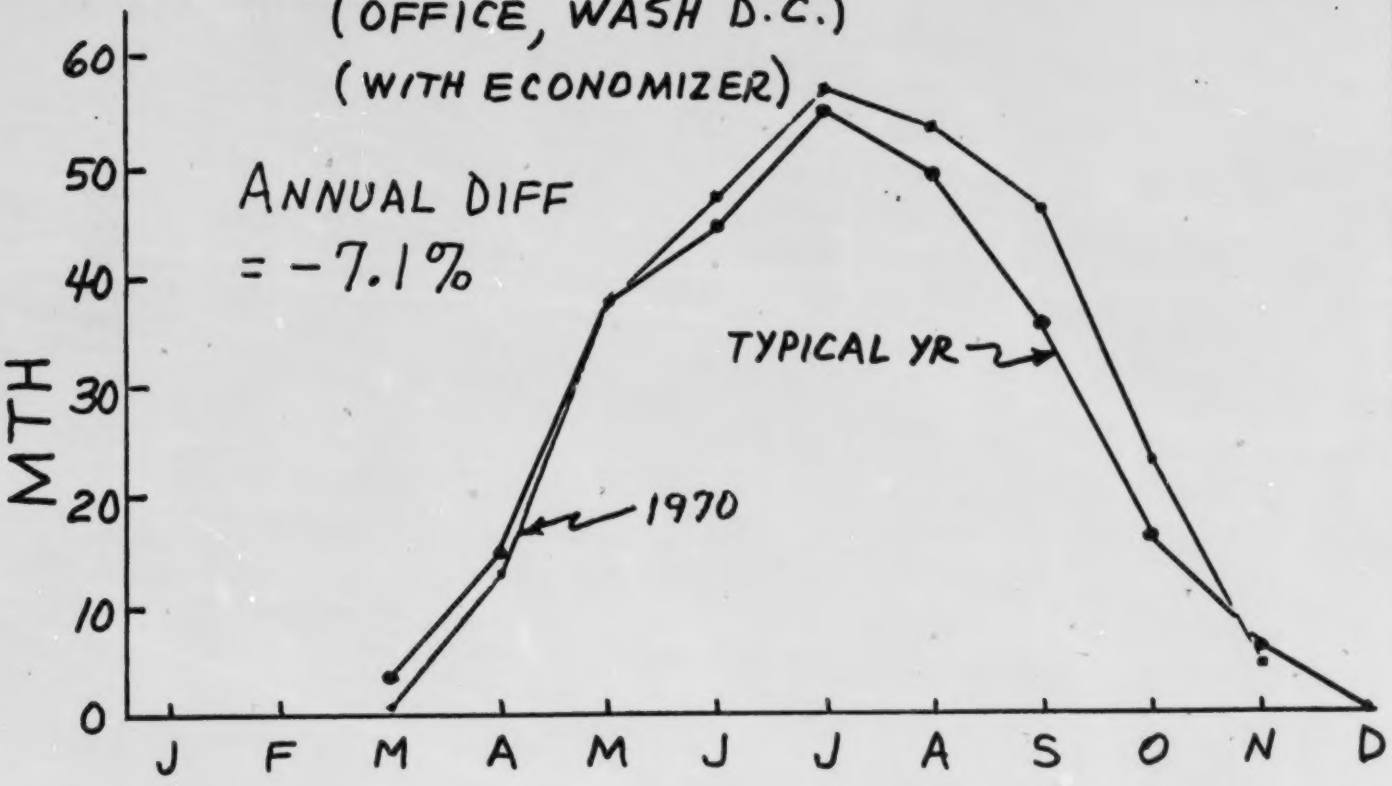
EFFECT OF WEATHER ON COOLING

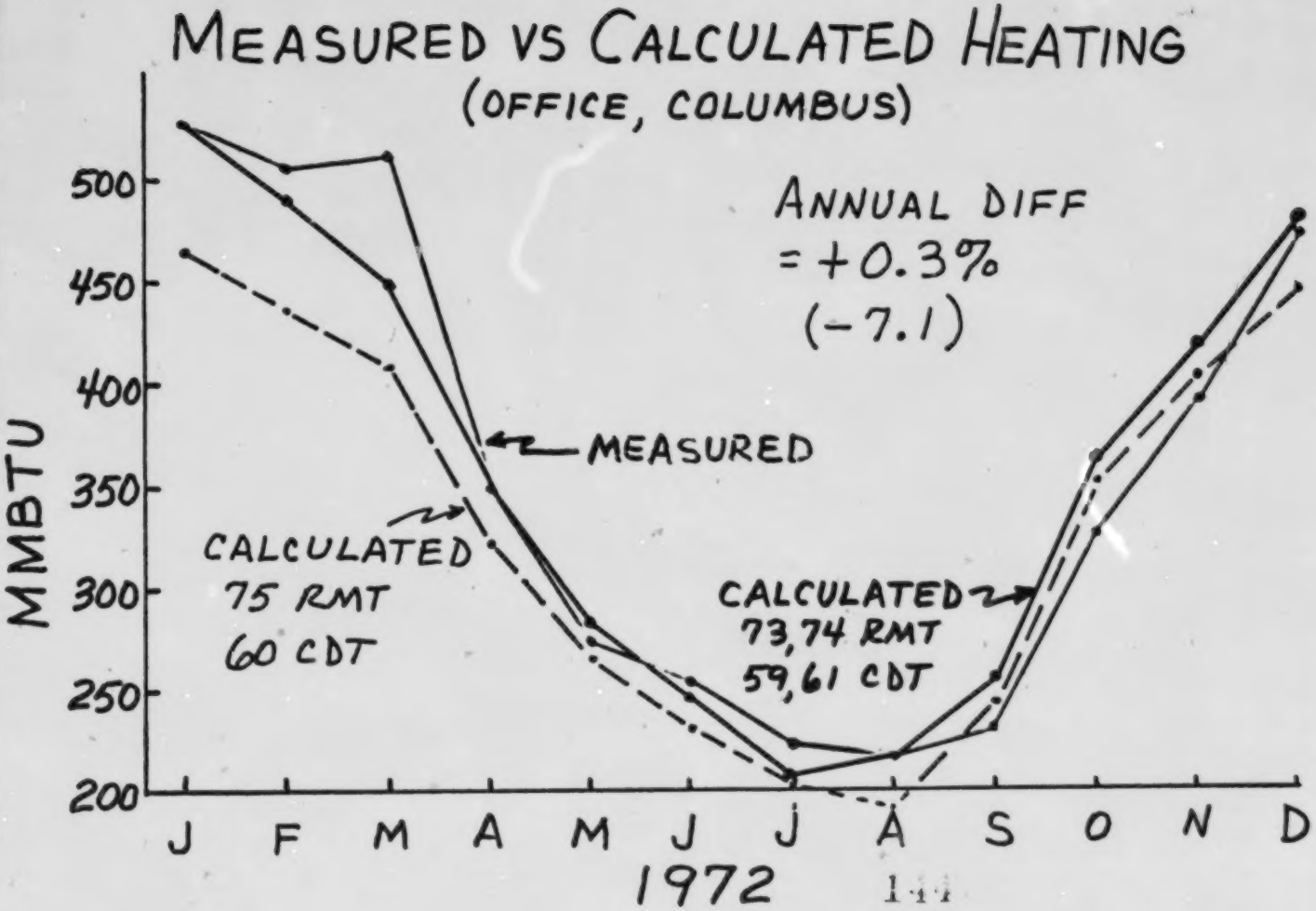


EFFECT OF WEATHER ON HEATING



EFFECT OF WEATHER ON COOLING




MEASURED VS CALCULATED HEATING
(OFFICE, COLUMBUS)
ANNUAL DIFF
= +0.3%
(-7.1)
MEASURED
CALCULATED
75 RMT
60 CDT
CALCULATED
73,74 RMT
59,61 CDT
MMBTU
500
450
400
350
300
250
200
J F M A M J J A S O N D
1972

CHANGING KEY PARAMETERS

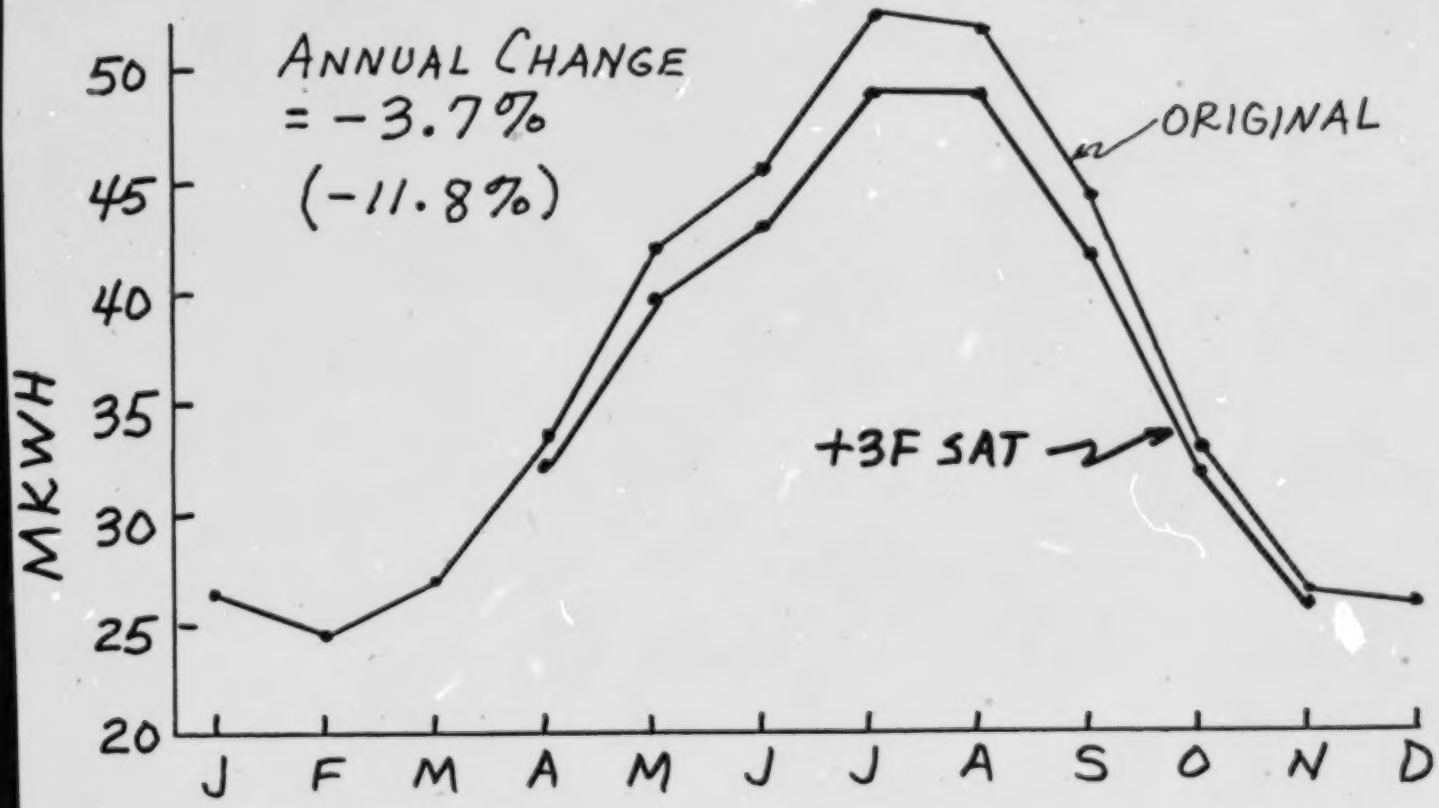
1. ESTABLISH MINIMUM CRITERIA
2. TRY TO GET ENERGY USE BY SOURCE
3. GROUP CHANGES BY CAPITAL COST
    a. CONTROL SETTINGS, OPERATIONAL PROCEDURES
    b. MINOR MODIFICATIONS
    c. MAJOR CHANGES IN BLDG/SYS

ELEC ENERGY USE BY SOURCE

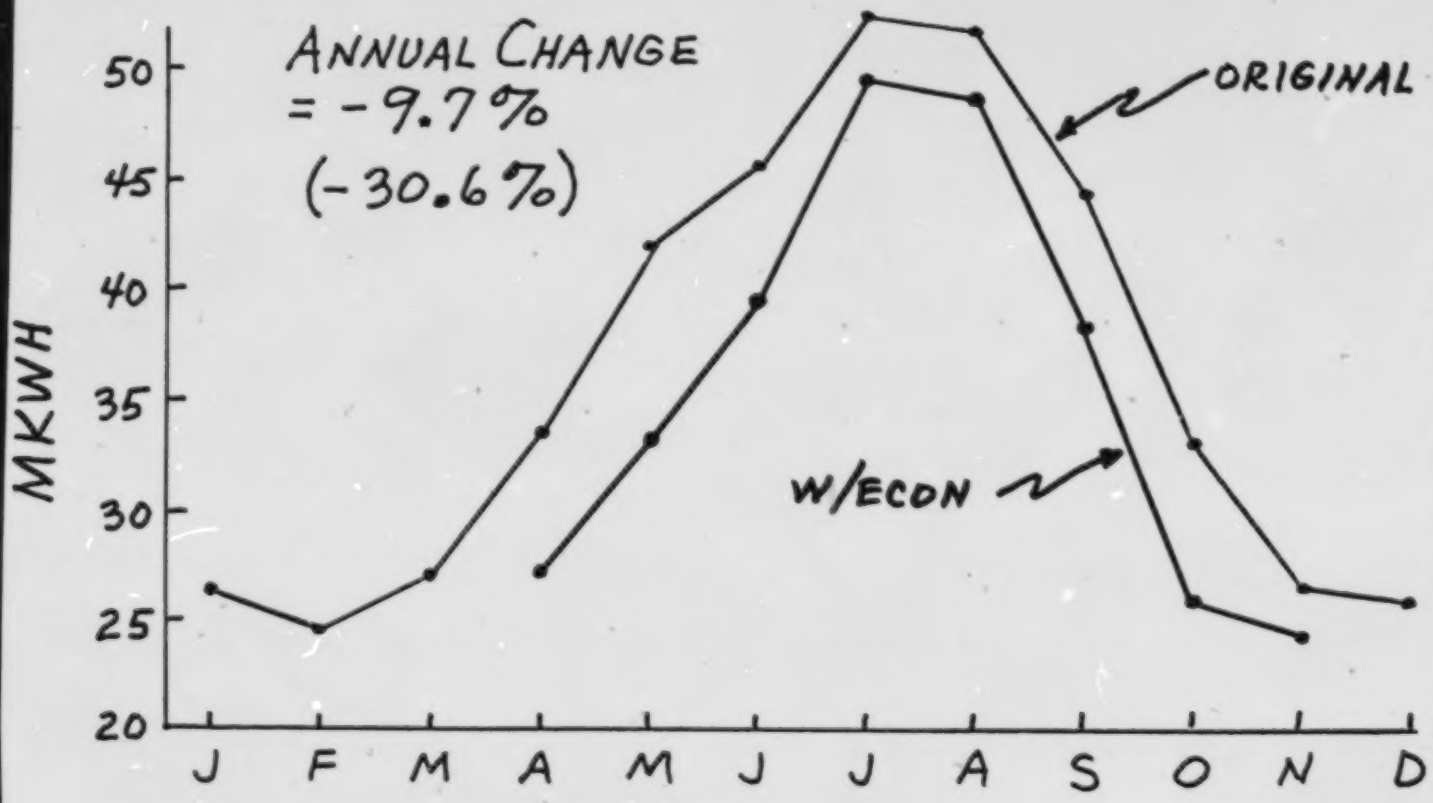
% OF TOTAL ELECTRIC

	SAN ANTONIO	RALEIGH	COLUMBUS	WASH	SAN FRAN
BASE	36.7	77.1	32.8	61.2	34.4
FANS	29.3	7.9	34.6	7.9	45.6
ACCES	11.3	3.1	8.1	5.3	9.4
CHLR	22.7	11.7	24.5	25.6	10.7

EFFECT OF INCREASED SUPPLY TEMPERATURE



EFFECT OF IMPROVED ECONOMIZER CONTROL

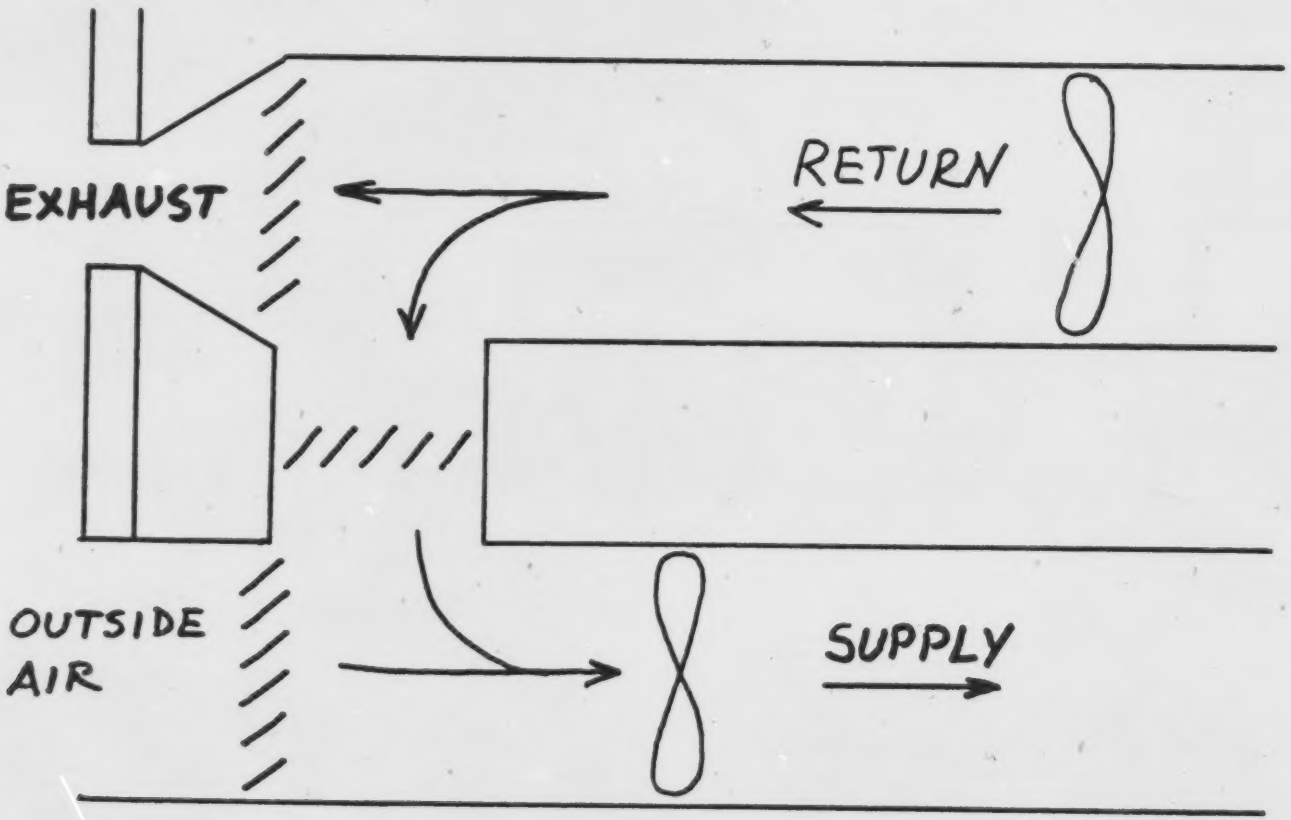


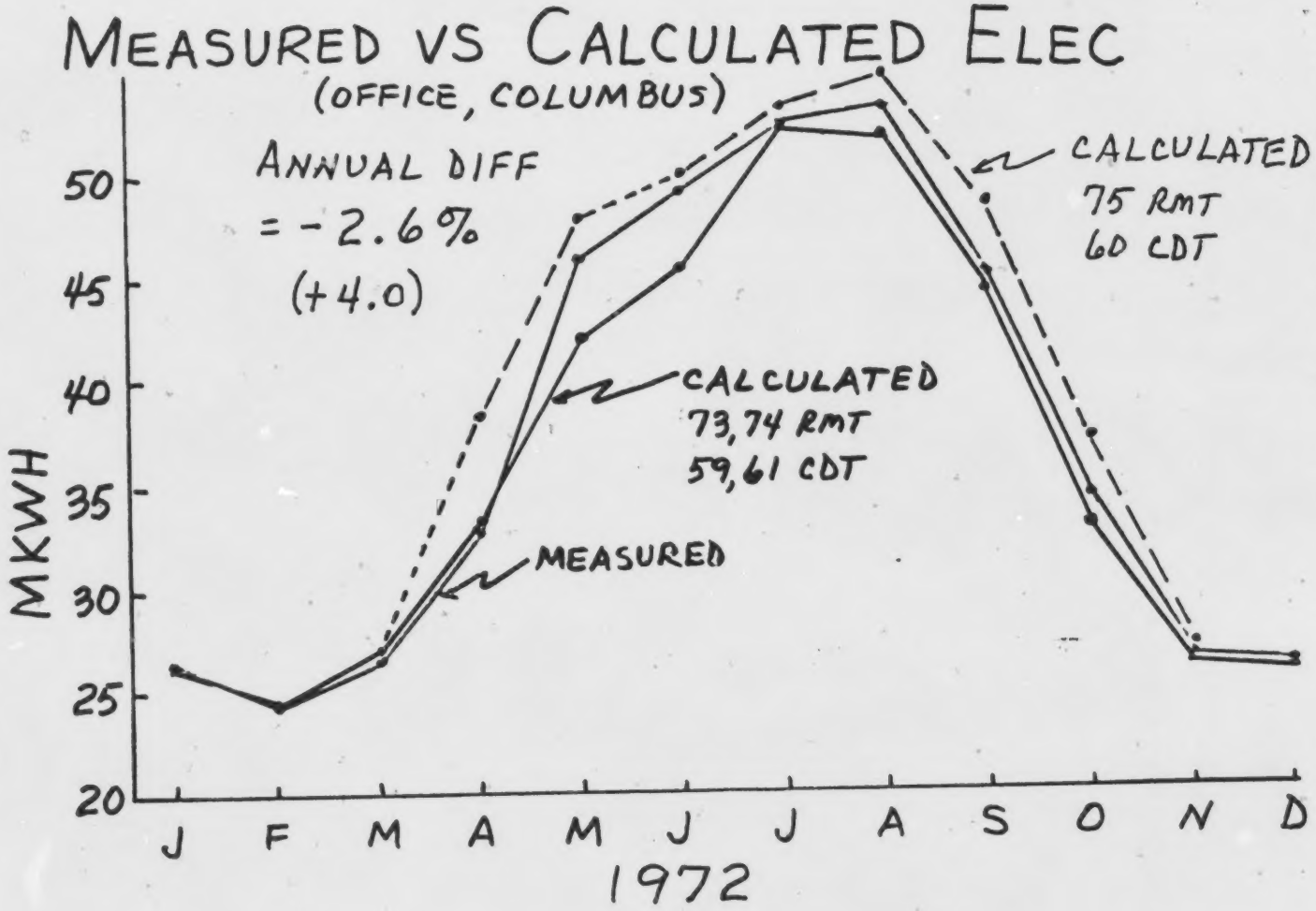
THERMAL EFFECTS OF VARIOUS CHANGES

VIRGINIA HIGH SCHOOLS

	D		J
	% CHG HEAT	% CHG COOL	% CHG HEAT
REDUCE LTS 15%	+ 8.2	- 9.8	+ 2.4
REDUCE O/A 50%	-31.8	- 1.5	-13.5
NO EXH AT NIGHT	- 6.5	+ 1.9	
SETBACK	-43.4	-43.2	-50.6

FLOW AT RETURN/OUTSIDE MIXING ZONE




MEASURED VS CALCULATED ELEC
(OFFICE, COLUMBUS)
ANNUAL DIFF
= -2.6%
(+4.0)
CALCULATED
75 RMT
60 CDT
CALCULATED
73,74 RMT
59,61 CDT
MEASURED
MKWH
50
45
40
35
30
25
20
J F M A M J J A S O N D
1972

OVERVIEW OF ESA PROGRAMS

The Energy System Analysis Series is a library of some 17 computer programs developed by Ross F. Meriwether and Associates, Inc. for hour-by-hour calculation of the annual energy consumption of various types of air-side systems and mechanical plants, for applying local utility rate schedules to these demands and consumptions, and for combining these costs with other owning and operating costs for year-by-year cashflow projections. Each major step in a complete energy system analysis is handled by a different program (five major programs are normally used in a typical analysis), thereby permitting the engineer to evaluate the results of one part before finalizing inputs and proceeding with the next part. The various programs permit the user to evaluate different air-side system types, various control temperatures, airflow quantities, operating schedules, heat recovery or economizer cycles, various equipment types and accessory combinations, competing energy sources, alternate utility rates, and the impact of various economic factors on total owning and operating costs.

The heart of the Series is The Energy Requirements Estimate program (ERE) which provides an 8760-hour closed-loop simulation of the building and its various air-side systems. Continuous simulation thru a full-year operating period permits the impact of various internal and external load variations, on-off or setback operating schedules, and control schedules to be evaluated in considerable detail. The program tracks the drift in overall space temperature during shut-off or setback periods, and tracks the response of the system during the pickup period when the system is reactivated. Virtually all of the classical and current types of air-side systems can be simulated, with many types of control options

superimposed on the basic system types. The basic system types are:

1. Single duct, constant volume, variable discharge temperatures set by space demand with no excess cooling or reheating.
2. Terminal reheat with scheduled cold coil discharge temperature during the cooling cycle.
3. Terminal reheat with scheduled cold coil discharge temperature during cooling or heating cycles.
4. Induction or fan-coil type system (four-pipe, two-pipe, or two-pipe changeover) with scheduled primary air temperature.
5. Terminal reheat with cold coil discharge temperature set by maximum demand of any section.
6. Dual-duct or multi-zone with scheduled hot and cold deck temperatures.
7. Dual-duct or multi-zone with deck temperatures set by greatest demand.
8. Split conduit system with single duct, constant volume, variable temperature system to offset transmission loads, and a variable volume system for solar and internal.
9. Standard variable volume, scheduled temperature system.
10. Two-duct/bypass, with terminal heating.

The program can handle both fixed point and dual point (including dead band) thermostat control of space temperature.

When used in conjunction with a solar table generating program (SL2), the ERE program permits evaluation of various glass types, orientation and tilt, and shading amounts, with the resulting solar loads treated as instantaneous or time-averaged.

Since the building and system design data are input items (design point loads are calculated in an external program or taken from manual calculations), the programs can be

used to simulate the actual conditions in existing buildings as well as proposed conditions for new buildings. The program does not "optimize" system characteristics but rather, simulates a specified set of characteristics to evaluate energy consumption and system response.

The programs have been developed in close coordination with a large number of practicing consulting engineers throughout the world. The programs are frequently modified on request to handle a specific feature that an engineer wishes to evaluate.

Primary public access to the program series is thru University Computing Company on their UNIVAC 1108 machines. Under certain circumstances, the library is installed on other machines on a private arrangement basis for a particular user.

Additional information is available from:

Ross F. Meriwether & Associates, Inc.
1600 N. E. Loop 410, Suite 241
San Antonio, Texas 78209

Phone: Area Code 512 824-5302

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SECTION VII

WHAT CAN BE LEARNED FROM COMPUTERIZED ENERGY ANALYSIS

OUTLINE

Ultimate Objective

How Much Energy is Required

How can Energy be Used Most Efficiently and Economically

Summary

WHAT CAN BE LEARNED FROM COMPUTERIZED ENERGY ANALYSIS

The ultimate objective of an energy management effort is to minimize operating expenses without eliminating necessary services. Both rising energy costs and fuel shortages have created a very real requirement for better control of energy use. Numerous predictions have been made with regard to the amount of energy savings available through conservation efforts. For buildings, these estimates range from 25 to more than 50% of pre-conservation consumption. Several colleges and universities have achieved savings of this order of magnitude in specific buildings and yet others have been unable to make significant progress beyond removing light bulbs and reducing service during evenings and weekends.

There appears to be several difficulties at the root of this situation:

- uncertainty as to the actual benefit of specific conservation activities
- uncertainty as to the "side effects" of conservation activities
- uncertainty as to the cost of implementing conservation activities and the rate of return which might be realized from the investment.

The latter concern may well be the primary factor. College and university physical plant budgets just don't have the slack to undertake a significant energy management effort

without specific support from the administration. On the other hand, administrators are under increasing financial pressure. They are frequently unable to invest even in the additional staff necessary to carry out an effective program without a clear indication of the benefits to be realized. This is, of course, made more difficult by the unfortunate fact that energy management efforts may not reduce operating costs, just reduce their rate of increase. In other words, the savings to be realized are in the form of "cost avoidance". It is therefore necessary to be able to clearly document every aspect of the program -- to eliminate the uncertainty to the greatest possible extent.

Information is required. It is necessary to be able to clearly define what can be done, what should be done, how much it will cost initially, and what can be saved. In beginning this discussion of energy analysis, two questions were asked:

- How much energy is required to maintain comfort and supply necessary utility service in a building?
- How can the buildings actual energy needs be met most efficiently and economically?

Answering these questions will contribute significantly to removing the uncertainties mentioned above. The intent of the material presented in the previous sections has been to demonstrate that computerized energy analysis, in the form of energy audits and simulation procedures, provide an effective means of answering these questions.

How Much Energy Is Required:

Unfortunately, the answer to the "how much energy is required" question is not whatever amount of energy we are now using. As a general rule we know little about how we use energy and how much is really required. Thus, the first objective is to determine how we use energy on a building by building basis. This evaluation must be on an end-use basis -- lights, office or special equipment, air moving equipment, heating and cooling etc. There would be at least two ways to determine this:

. Measure consumption, item by item

. Estimate consumption using audit and simulation procedures

Considering the complexity of building use and system interactions, and the number of variables involved, measuring consumption by end-use requires a substantial effort. This is an effort, however, that should be carefully evaluated as it has many long-term benefits. But there is a limit to the usefulness of this approach. Certainly energy use by source should be determined at the building level and recorded on a reasonable time scale such as a day. The cost of instrumentation and the difficulty of managing and utilizing measured data much beyond this level however is a research effort, not an energy management effort. (The notable exception to this is the automated control system which allows you to record, store and retrieve information for system control and

maintinence purposes) Even when complete data is available, it must be collected and evaluated on a real-time basis. Thus, it would require a year of actual time to track the energy requirements of various items on an annual basis. Additionally, one is faced with the difficulty of trying to assess the impact of the variables that are uncontrolled (and sometimes unknown) such as space use, control functions that may be modified and climatic factors. This is a complicated and time consuming task.

As an alternative, the audit and simulation procedures provide a means of obtaining information on energy use in a much compressed time frame. With the modeling and simulation processes, it is possible to examine the effects of parameter variation on an individual and independent basis. A model may be established as relevant by comparison based on the performance of individual system and building components and aggregate energy consumption. Once this has been done, the computer analysis can be used to provide the necessary dissaggregation to end use consumption. This can be done quickly and for a controlled set of input assumptions which will demonstrate the influence of each variable of concern. Thus the computerized analysis, although only an "estimate", may have a higher information content than measured data because the variable inputs are known specifically. The major advantage of the computerized approach is the time required. Once the analysis procedures have been established, personnel trained and the computer program debugged,

a buildings' energy needs can be evaluated in a matter of days with computer time requirements on the order of minutes. With a flexible program, these needs may be identified at the level of the systems ability to control a particular space or group of spaces. By identifying energy consumption on the basis of end-use, a rational determination can be made as to which areas represent major energy use and therefore significant opportunity for energy conservation and cost benefits.

How Can Energy Be Used Most Efficiently and Economically:

As noted previously, buildings and their systems are complex and interact in ways that are often difficult to predict. However, once the building and system simulation input data have been gathered, a number of options can be evaluated very quickly. This is perhaps the major advantage of the computerized energy analysis process.

For example, it is possible to determine both the energy savings and variation in space temperatures associated with shuting the system down for a specified period such as overnight or for a weekend. Or how much can be saved by reducing lighting if the supply air delivered is also reduced as opposed to leaving it at the design level (this is particularly important in double duct and reheat systems). Or what are the effects of raising chilled water temperatures a few degrees to improve the equipment C.O.P., both in terms of savings and ability to provide comfort control. Specific answers can be

obtained for specific questions with relatively little effort.

The only qualification on the above is that all existing programs are presently limited in the number of standard systems and control options they will handle without modifying subroutines or writing new program elements. However, the available programs do cover the majority of the systems which have been used in recent years and modifications to fit a particular circumstance may often be accomplished relatively easily once personnel become familiar with the program.

Two case studies describing the application of computer assisted energy analysis are included in this workbook as an appendix. They illustrate both the process and the results which may be obtained. The reader is directed to them to see more specifically what may be accomplished by these procedures.

Summary:

It has been the intent of this entire seminar presentation to demonstrate that with proper care in selecting and managing energy analysis programs, or in choosing commercial services to accomplish the same purposes, Universities and Colleges may derive significant benefits from efficient and economical use and management of their facilities.

TRACE VERSION V00200

TRACE-DIRECT ENERGY SYSTEM AND ECONOMIC ANALYSIS FOR NEW AND EXISTING BUILDINGS

Presented by:

JIM DUDLEY
APPLICATIONS ENGINEERING
THE TRANE COMPANY
LA CROSSE, WISCONSIN 54601

Presented to:

THE ASSOCIATION OF PHYSICAL PLANT
ADMINISTRATORS OF UNIVERSITIES
AND COLLEGES
PITTSBURGH, PENNSYLVANIA
APRIL 14, 1977

Existing Buildings

100 —

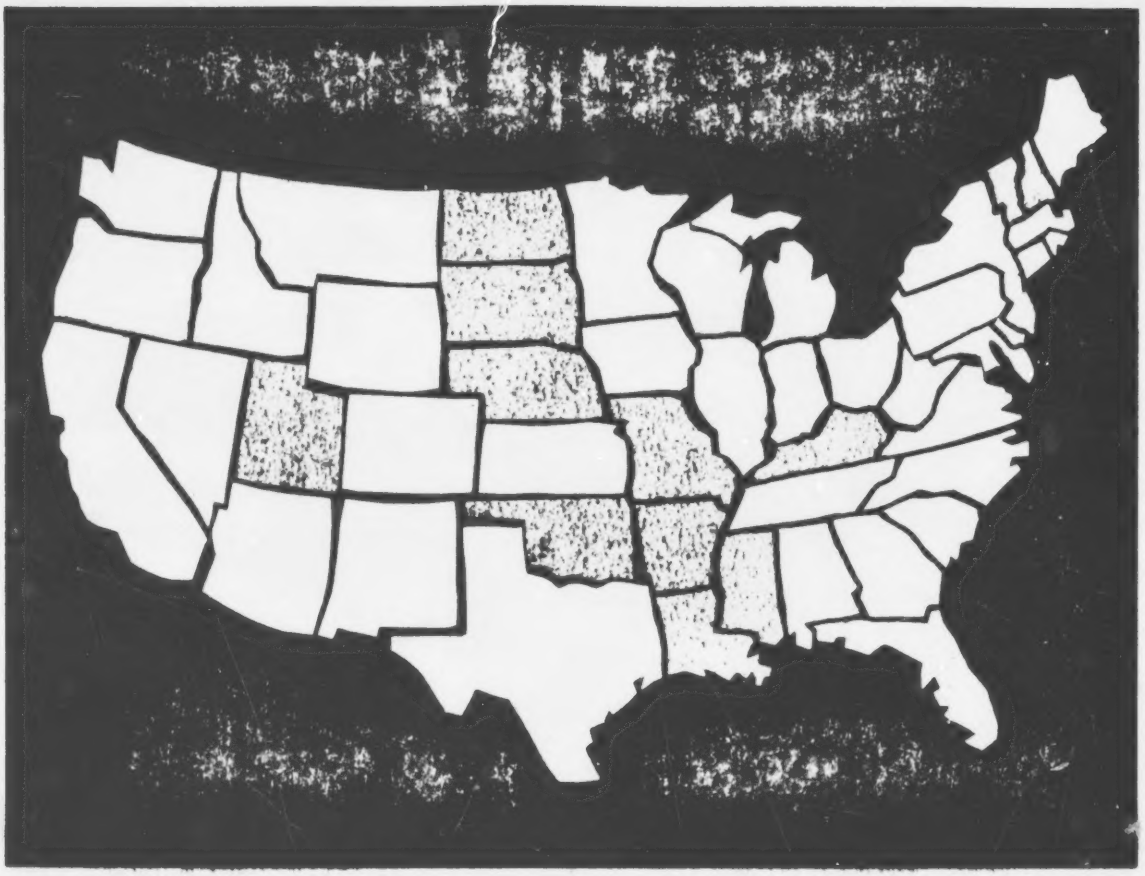
ENERGY AND ECONOMIC ANALYSIS OF BUILDINGS

APPROXIMATELY THREE YEARS AGO, ASHRAE MADE AN AGREEMENT WITH THE NATIONAL CONFERENCE OF STATES ON BUILDING CODES AND STANDARDS TO DEVELOP A CONSENSUS STANDARD OF GUIDELINES TO CONSERVE ENERGY IN NEW BUILDING CONSTRUCTION.

THE RESULT WAS ASHRAE STANDARD 90-75 WHICH WAS ADOPTED IN AUGUST OF 1975. THIS STANDARD WILL ALSO BE SUBMITTED TO THE AMERICAN NATIONAL STANDARDS INSTITUTE TO BECOME AN ANSI STANDARD.

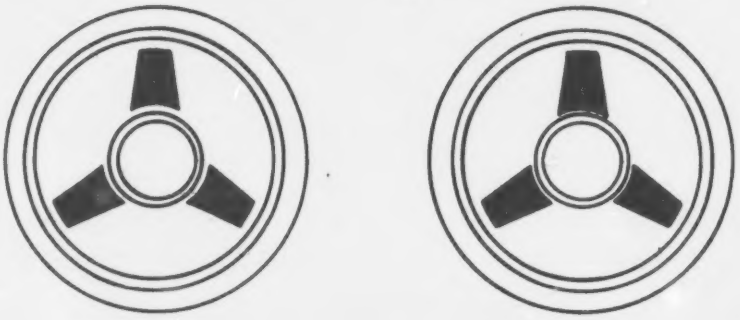
ASHRAE AT THE ANNUAL MEETING IN DALLAS IN JANUARY OF 1976 OFFICIALLY COMMISSIONED THE WRITING OF AN ENERGY CONSERVATION STANDARD FOR EXISTING BUILDINGS. EVENTUALLY, WHEN COMPLETED, THESE STANDARDS WILL BE KNOWN AS ASHRAE STANDARD 100-77 SERIES. THESE NEW STANDARDS WILL BE WRITTEN BY A NUCLEUS OF KEY INDUSTRY EXPERTS AND OTHER VOLUNTEERS WHO WROTE THE ASHRAE STANDARD 90-75 THAT PERTAINS TO NEW BUILDING CONSTRUCTION.

AS A RESULT OF ASHRAE STANDARD 90-75, APPROXIMATELY 35 STATES SHOWN IN GREEN HAVE SAID THEY ARE GOING TO USE ASHRAE STANDARD 90-75 IN PART OR IN TOTAL AS A PART OF THEIR BUILDING CODE. AT THE LAST ASHRAE MEETING IN CHICAGO IN FEBRUARY OF THIS YEAR, A MODEL CODE WAS PRESENT FOR CONSENSUS REVIEW.



CHAPTER 10

90 - 75



IF ADOPTED, THIS CODE WILL FORM THE BASIS FOR STAGE ENERGY LEGISLATION TO CONSERVE ENERGY IN NEW BUILDING CONSTRUCTION.

I'D LIKE FOR A MINUTE TO TAKE YOU BACK TO ASHRAE STANDARD 90-75. AS MANY OF YOU KNOW, THIS STANDARD HAS A TOTAL OF 11 SECTIONS AT THE PRESENT TIME. SECTIONS 4 THROUGH 9 ESTABLISH BUILDING COMPONENT PERFORMANCE STANDARDS, KNOWN AS THE PRESCRIPTIVE PORTION THAT MUST BE FOLLOWED BY DESIGNERS FOR DESIGNING NEW ENERGY EFFICIENT BUILDINGS. THESE SECTIONS COVER SUCH THINGS AS THE ENVELOPE, SYSTEM, EQUIPMENT, HOT WATER HEATING, POWER DISTRIBUTION, LIGHTING, ETC.

ALSO INCLUDED IN STANDARD 90-75 IS A CHAPTER 10 WHICH PROVIDES THE DESIGNER WITH FLEXIBILITY TO USE AN ALTERNATE DESIGN IF HE CAN SHOW THAT IT CONSUMES EQUAL OR LESS ENERGY THAN THE BUILDING DESIGNED IN ACCORDANCE WITH SECTIONS 4 THROUGH 9. FOR EXAMPLE, IT ALLOWS THE DESIGNER TO MAKE ARCHITECTURAL AND SYSTEM TRADE-OUTS FOR LOWER ENERGY CONSUMPTION. FORTUNATELY, THE COMPUTER MAKES SUCH ANALYSIS RELATIVELY EASY.

ALTHOUGH SECTION 10 OF ASHRAE STANDARD 90-75 DOES NOT SPECIFICALLY CALL FOR COMPUTERIZED ENERGY ANALYSIS,

IT DOES SET FORTH THE REQUIREMENTS FOR ENERGY ANALYSIS IN BUILDINGS AND BECAUSE OF THE COMPLEXITY OF THE SUBJECT, IT IS GENERALLY ACCEPTED THAT THE COMPUTER IS THE TOOL TO ACCOMPLISH THE TASK.

IT IS ALSO A FACT THAT THE STANDARD WILL CREATE A NEED FOR COMPREHENSIVE ENERGY AND ECONOMIC ANALYSIS OF BUILDINGS. TO ANSWER THIS NEED, THERE ARE SEVERAL PROGRAMS AVAILABLE TO THE INDUSTRY TODAY. I WOULD LIKE TO FIRST GIVE YOU A BRIEF OVERVIEW OF THE MOST WIDELY USED PROGRAMS IN OUR INDUSTRY TODAY AND THEN I WILL ATTEMPT TO TAKE YOU THROUGH THE ONE THAT I KNOW THE MOST ABOUT, NAMELY, THE TRACE PROGRAM WHICH IS OFFERED TO ENGINEERS AS A SERVICE BY THE TRANE COMPANY FOR A FEE.

THE FOUR MOST WIDELY USED PROGRAMS IN EXISTENCE TODAY ARE AXCESS
E CUBE
ESA
TRACE

THERE ARE SEVERAL OTHER PROGRAMS AVAILABLE ON A LOCALIZED BASIS. HOWEVER, TIME DOES NOT PERMIT GOING INTO THESE AT THIS TIME.

IN ADDITION, THERE ARE OTHER PROGRAMS THAT ARE UNDER DEVELOPMENT AT THIS POINT IN TIME THAT WE WILL NOT ELABORATE ON DUE TO THE TIME LIMITATIONS.

THE AXCESS PROGRAM IS A PROGRAM OFFERED BY THE ELECTRIC UTILITIES. THE E CUBE PROGRAM IS OFFERED BY THE GAS UTILITIES, THE ESA PROGRAM OR ENERGY SYSTEMS ANALYSIS PROGRAM IS OFFERED BY ROSS MERRIWEATHER AND ASSOCIATES WHOM YOU LISTENED TO YESTERDAY AND THE TRACE PROGRAM WHICH IS CALLED TRANE AIR CONDITIONING ECONOMICS IS OFFERED BY THE TRANE COMPANY THROUGH OUR LOCAL OFFICES AND REMOTE COMPUTING UTILITIES.

ALL OF THE PROGRAMS THAT I HAVE MENTIONED ARE OFFERED ON REMOTE COMPUTER UTILITY SERVICE.

FOR A USER TO BECOME TOTALLY FAMILIAR WITH ALL FOUR OF THESE PROGRAMS IN DEPTH TO THE EXTENT THAT HE CAN USE THEM EFFECTIVELY IS A VIRTUAL IMPOSSIBILITY. I MENTIONED THAT THE OTHER PROGRAMS EXIST SO AS NOT TO MISLEAD YOU INTO THINKING THAT THE TRACE PROGRAM IS THE ONLY PROGRAM THAT CAN ACCOMPLISH ENERGY AND ECONOMIC ANALYSIS OF BUILDINGS.

I AM, HOWEVER, GOING TO LIMIT MY REMARKS TODAY TO THE TRACE PROGRAM SINCE IT IS THE PROGRAM THAT I AM MOST FAMILIAR WITH, HAVING BEEN INVOLVED WITH IT FOR APPOXIMATELY FOUR YEARS.

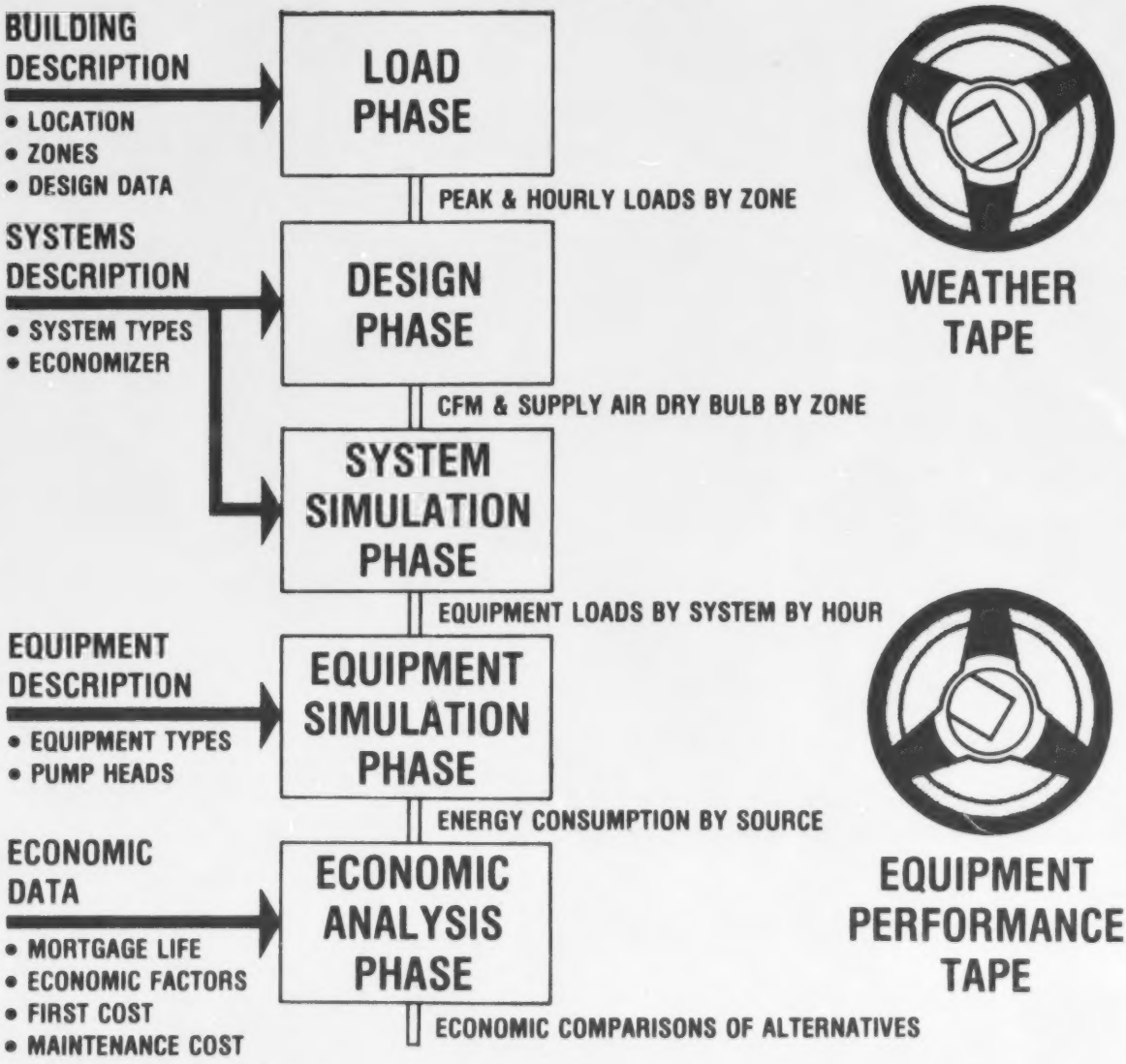
IN THE NEXT 2-1/2 HOURS I'D LIKE TO WALK YOU THROUGH WHAT WE BELIEVE SHOULD BE INCLUDED IN A MEANINGFUL ENERGY AND ECONOMIC ANALYSIS PROGRAM FOR BOTH NEW AND EXISTING BUILDING CONSTRUCTION.

IN THE CASE OF NEW BUILDING CONSTRUCTION, THE PROGRAM IS A TOOL TO THE SYSTEM DESIGNER TO HELP HIM SET THE PROPER DIRECTION OF DESIGN IN THE BEST INTERESTS OF THE OWNER TO SAVE ENERGY AND ENERGY DOLLARS OVER THE LIFE OF THE BUILDING.

IN THE CASE OF EXISTING BUILDING CONSTRUCTION, IT ALLOWS THE ENERGY MANAGER TO EVALUATE HIS CURRENT BUILDING SYSTEM EQUIPMENT DESIGN AND, MORE IMPORTANTLY, TO EVALUATE THE EFFECT OF CHANGES TO THE DESIGN TO SAVE ENERGY AND ENERGY DOLLARS. IT IS A TOOL TO QUANTIFY THE ENERGY CONSERVATION EFFECT OF VARIOUS CHANGES TO THE EXISTING BUILDINGS ON THE BASIS OF LIFE CYCLE COST.

TRACE FLOWCHART

VERSION V00100



SAID ANOTHER WAY, IT EVALUATES THE ECONOMIC IMPACT OF POSSIBLE ENERGY SAVING ALTERNATIVES TO JUSTIFY RENOVATION OF EXISTING BUILDINGS THROUGH ARCHITECTURAL, HVAC SYSTEMS AND EQUIPMENT MODIFICATION OR REPLACEMENT.

TO BEST UNDERSTAND THE TRACE PROGRAM, I'D LIKE TO GIVE YOU A BRIEF OVERVIEW OF THE PROGRAM. WE CALL IT TRACE VERSION 200. HOWEVER, TO BEST UNDERSTAND TRACE VERSION 200 YOU MUST FIRST UNDERSTAND TRACE VERSION 100 WHICH WAS THE ORIGINAL PROGRAM ANNOUNCED TO OUR INDUSTRY IN 1973.

TRACE ALLOWS YOU TO CONSIDER EACH ENERGY AND ENERGY RELATED ECONOMIC ASPECT OF A BUILDING, ITS ARCHITECTURAL DESIGN, ITS SYSTEM, ITS EQUIPMENT, ITS USE OCCUPANCY AND ECONOMIC GOALS. HERE'S HOW IT WORKS:

LOAD - ON NEW BUILDINGS YOU DO NOT HAVE TO INPUT THERMAL LOADS WITH TRACE. TRACE ACCEPTS YOUR BUILDING'S ARCHITECTURAL DESCRIPTION AND LOCATION AND THEN CALCULATES PEAK AND HOURLY LOADS BY ZONE, USING HOURLY CLIMATIC DATA FROM U.S. WEATHER BUREAU TAPES.

DESIGN - ZONE CFM, FAN CFM AND SUPPLY AIR DRY BULB TEMPERATURES ARE CALCULATED IN ADDITION TO DESIGN HEATING AND COOLING SYSTEM LOADS IN THE DESIGN PHASE.

SYSTEM SIMULATION - THE TRACE PROGRAM TRACKS THE PERFORMANCE OF THE AIR CONDITIONING, HEATING AND VENTILATING SYSTEM BY HOUR BY ZONE OVER ONE YEAR'S SYSTEM OPERATION. IT TRANSLATES BUILDING HEAT GAINS AND LOSSES INTO EQUIPMENT LOADS.

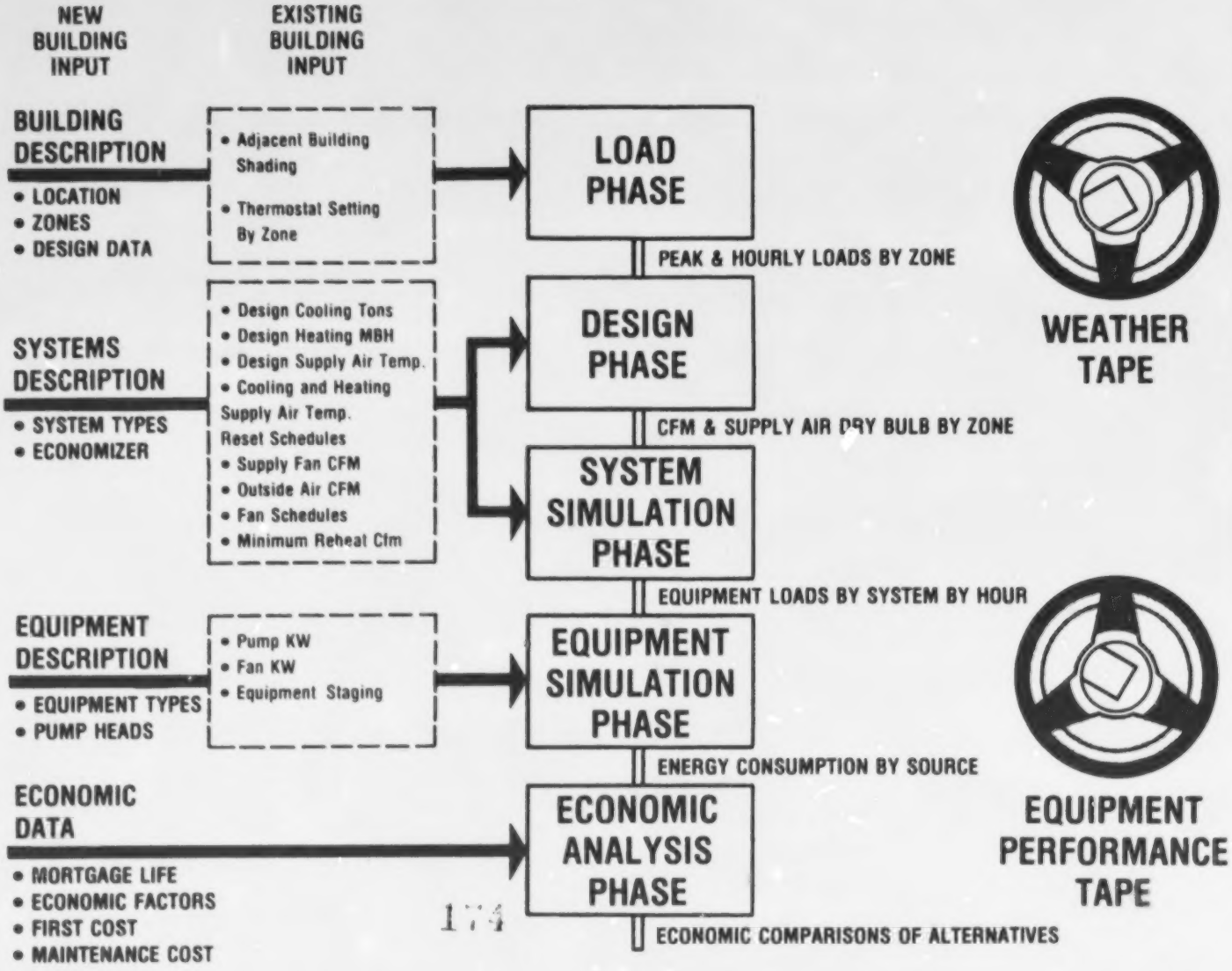
EQUIPMENT SIMULATION - THE EQUIPMENT LOADS ARE APPLIED TO FULL AND PART LOAD PERFORMANCE OF ALL HEATING, VENTILATING AND AIR CONDITIONING EQUIPMENT AND ACCESSORIES. THE PROGRAM ALREADY CONTAINS PART LOAD EQUIPMENT PERFORMANCE DATA. DESIGNERS ARE NOT REQUIRED TO INPUT PART LOAD PERFORMANCE.

ECONOMIC EVALUATION -

ENERGY CONSUMPTION IS CONVERTED INTO ENERGY DOLLARS USING THE ACTUAL UTILITY RATE SCHEDULE. LIFE CYCLE ECONOMIC FACTORS SUCH AS BOND LIFE, FIRST COST, MAINTENANCE COST, INSURANCE, ETC., ARE USED TO OBTAIN ECONOMIC COMPARISONS FOR THE VARIOUS ALTERNATIVES ON A LIFE CYCLE COST BASIS TO DETERMINE THE BEST LIFE CYCLE COST DESIGN.

FROM EXPERIENCE, WE HAVE LEARNED THAT AN EXISTING BUILDING ENERGY ANALYSIS CAN BE MORE COMPLEX THAN A NEW BUILDING ENERGY ANALYSIS. THE COMPLEXITIES ARE

TRACE FLOWCHART
VERSION V00200



CAUSED BY THE LIVING PATTERNS THAT HAVE DEVELOPED IN THE BUILDING SINCE IT WAS ORIGINALLY CONSTRUCTED.

ALSO, COMPLEXITIES ARE CAUSED BY THE FACT THAT AIR CONDITIONING IS STILL A RELATIVELY NEW TECHNOLOGY AND, IN THE PAST 25 YEARS, AIR CONDITIONING TECHNOLOGY HAS BECOME MUCH MORE OF A PRECISE SCIENCE. FOR THIS REASON, IN MANY EXISTING BUILDINGS, THE SYSTEMS AND HVAC EQUIPMENT ALREADY INSTALLED ARE SIGNIFICANTLY OVERSIZED BY TODAY'S DESIGN STANDARDS.

OBVIOUSLY, AN ACCURATE ENERGY ANALYSIS MUST MODEL THE EXISTING SITUATION IN AN EXISTING BUILDING BEFORE IT CAN ASSESS THE ENERGY IMPACT OF NEW CHANGES TO UPGRADE THE BUILDING SYSTEM EQUIPMENT ENERGY EFFICIENCY.

TRACE VERSION 200 HAS THE CAPABILITY OF MODELING THE EXISTING BUILDING SITUATION. SPECIFICALLY, IT ALLOWS SETTING OF VALUES THAT EXIST IN OLDER BUILDINGS THAT MIGHT NOT BE TAKEN INTO ACCOUNT IN NEW BUILDING DESIGNS. FOR EXAMPLE, IT ALLOWS THE USER TO ACCOUNT FOR ADJACENT BUILDING SHADING.

IT ALLOWS INDIVIDUAL THERMOSTAT SETTINGS PER THERMAL ZONE OF THE BUILDING TO REFLECT ITS ACTUAL UTILIZATION.

IT ALLOWS INPUT OF ACTUAL INSTALLED COOLING, HEATING AND AIR MOVING CAPACITIES AS WELL AS MEASURED OUTSIDE AIR QUANTITIES.

IT PERMITS INPUT OF ACTUAL SUPPLY AIR TEMPERATURES AND THEIR RESET SCHEDULE TO REFLECT ACTUAL BUILDING SYSTEM OPERATION PROCEDURES AS THE BUILDING EXISTS TODAY.

IT ALLOWS IMPUT OF THE ACTUAL OPERATING SCHEDULES OF COOLING, HEATING AND FAN EQUIPMENT AS IT'S BEING USED IN THE BUILDING.

IT ALLOWS INPUT OF MEASURED PUMP KW AND FAN KW REFLECTING EQUIPMENT ACTUAL OPERATING POINTS AS OPPOSED TO DESIGN OPERATING POINTS WHEN THE SYSTEM WAS ORIGINALLY DESIGNED. THIS REFLECTS EQUIPMENT FOULING WEAR, ETC.

IT ALLOWS INPUT OF THE EQUIPMENT STAGING AS IT IS ACTUALLY BEING OPERATED TO SATISFY THE BUILDING ENVIRONMENTAL CONTROL REQUIREMENTS.

THESE ARE ALL IMPORTANT ITEMS BECAUSE THEY ALLOW THE PROGRAM TO REFLECT THE ACTUAL SITUATION OF BUILDING OPERATION AS IT EXISTS RATHER THAN HOW IT WAS DESIGNED TO EXIST YEARS AGO.

THIS IS IMPORTANT BECAUSE USING TRACE ON AN EXISTING BUILDING ENERGY REDUCTION PROGRAM IS A TWO-STEP PROCESS.

THE FIRST STEP IS TO DETERMINE HOW WELL THE BUILDING'S ENERGY SYSTEM IS PERFORMING AT THE PRESENT TIME VERSUS THE PERFORMANCE OF THE ENERGY SYSTEM AS INTENDED WHEN ORIGINALLY INSTALLED. THIS HELPS ASCERTAIN WHAT NEEDS TO BE DONE TO TRIM OR ADJUST THE ENERGY SYSTEM TO OBTAIN THE ORIGINAL EFFICIENCY OF OPERATION.

RUNNING TRACE VERSION 200 AND THEN COMPARING THESE RESULTS AGAINST THE ACTUAL UTILITY BILLS TELLS ONE HOW THE PRESENT BUILDING IS PERFORMING. THE DETAILED OUTPUT VALUES IN TRACE 200 THEN PROVIDE THE DATA NECESSARY TO ANALYZE AND FIND THE AREAS THAT NEED TRIMMING OR ADJUSTMENT.

THE SECOND STEP IS TO EVALUATE PHYSICAL CHANGES THAT CAN REDUCE THE ENERGY. THESE CHANGES ARE INPUT INTO TRACE 200 AND THE OUTPUT COMPARES THEM TO THE PRESENT BUILDING. AT THE SAME TIME, TRACE PROVIDES AN ECONOMIC LIFE CYCLE COMPARISON TO HELP DETERMINE WHETHER OR NOT THE CONTEMPLATED CHANGES ARE ECONOMICALLY JUSTIFIED.

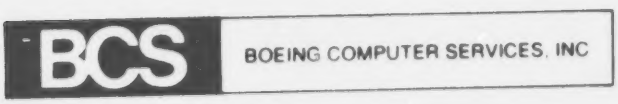
MOST ENGINEERS RECOGNIZE THAT ENERGY ANALYSIS IS A VERY COMPLEX BUSINESS, AND EXPERTS AREN'T MADE OVERNIGHT.

FOR THIS REASON, THE TRANE COMPANY HAS DEVELOPED A MEANS FOR BUILDING AND SYSTEM DESIGNERS AS WELL AS ENGINEERING ENERGY MANAGERS TO BECOME PROFICIENT IN ENERGY ANALYSIS WITH A MINIMUM OF INVESTMENT OF TIME AND MONEY. THIS MEANS IS WHAT WE CALL THE TRACE-DIRECT PROGRAM.

THE PURPOSE BEHIND THE TRACE-DIRECT PROGRAM IS TO PERMIT THE AVERAGE BUILDING SYSTEM DESIGNER OR ENGINEERING ENERGY MANAGER TO EASILY USE TRACE WITHOUT HELP AND THROUGH ITS USE HAVE ENERGY ANALYSIS CAPABILITY.

SINCE TRACE WAS ORIGINALLY INTRODUCED IN 1973, THERE HAS DEVELOPED THE NEED BY FREQUENT USERS TO HAVE FAST TURN-AROUND TIME OF COMPUTER OUTPUTS. FURTHER, THERE HAS DEVELOPED THE NEED BY MANY USERS TO HAVE A KNOWLEDGE OF THE EXACT MATHEMATICAL COMPOSITION OF TRACE AS WELL THE FUNCTION-BY-FUNCTION FLOW PROCEDURES USED WITHIN THE TRACE PROGRAM. THIS IS NEEDED BY USERS TO INSURE THE SIMULATION PROCEDURES ARE CORRECTLY DUPLICATING THE OPERATION OF THE SPECIFIC HVAC SYSTEM.

MCAUTO
MCDONNELL DOUGLAS AUTOMATION COMPANY


BCS
BOEING COMPUTER SERVICES, INC

CONSEQUENTLY, WE MADE TWO IMPORTANT MOVES IN THE FIRST QUARTER OF 1976 IN REGARD TO TRACE.

FIRST, THE TRACE PROGRAM WAS PLACED ON THE COMPUTER FACILITIES OF MCAUTO, FORMERLY KNOWN AS MCDONALD-DOUGLAS AUTOMATION COMPANY, AND BCS, FORMERLY KNOWN AS BOEING COMPUTER SERVICES, INC. THIS ALLOWS THE USE OF TRACE ON A TIME-SHARING BASIS. THE TURN-AROUND TIME OF OUTPUT IS NOW A MATTER OF MINUTES INSTEAD OF DAYS AS BEFORE.

SECOND, TO ALLOW THE TRACE-DIRECT USER TO GAIN AN UNDERSTANDING OF TRACE AND TO INSURE THE PROGRAM CAN BE USED SUCCESSFULLY, AN EXTENSIVE AND INTENSIVE TRAINING PROGRAM IS CONDUCTED. THIS TRAINING PROGRAM TEACHES THE EXACT MATHEMATICAL COMPOSITION OF TRACE ON A FUNCTION-TO-FUNCTION BASIS. SINCE THESE ACTIVE USERS HAVE ALREADY GAINED AN OPERATIONAL UNDERSTANDING OF TRACE, THIS DETAILED KNOWLEDGE ALLOWS THEM TO ACCOMPLISH VERY SOPHISTICATED ENERGY ANALYSIS VERY SIMPLY AND QUICKLY WITHOUT ERRORS.

IN ADDITION, FROM OUR EXPERIENCE IT IS NECESSARY TO SUPPORT EACH TRACE-DIRECT USER WITH A LOCALLY BASED ENGINEER TO ANSWER QUESTIONS RELATIVE TO THE USE OF

THE PROGRAM ON SPECIFIC PROJECTS. FURTHER, THESE ON-THE-SPOT ENGINEERS SUPPORT THE LOCAL McDONALD-DOUGLAS AND BOEING PERSONNEL RELATIVE TO THE ACCESS OF TRACE. THE FIELD ENGINEERS HAVE A WORKING PROFICIENCY WITH TRACE AND HAVE BEEN ESPECIALLY TRAINED TO HAVE AN OVERALL HVAC ECONOMIC CAPABILITY. AS A RESULT, THEY ARE VERY VALUABLE TO TRACE-DIRECT USERS.

SINCE THE INTRODUCTION OF TRACE IN 1973, IN EXCESS OF 750 FIRMS HAVE BEGUN USING TRACE ON A FREQUENT BASIS. THE TRACE-DIRECT PROGRAM WAS CONCEIVED PRIMARILY FOR THESE FIRMS.

APPROXIMATELY 600 TRACE-DIRECT USERS HAVE BEEN TRAINED SINCE THE BEGINNING OF THE SECOND QUARTER OF 1976. THIS REPRESENTS IN EXCESS OF 200 ENGINEERING FIRMS LOCATED IN SEVERAL CITIES THROUGHOUT THE UNITED STATES. SOME OF THE MOST PRESTIGIOUS CONSULTING ENGINEERING FIRMS IN THE NATION WERE THE FIRST FIRMS TRAINED. IN ADDITION, SEVERAL CORPORATIONS AND UNIVERSITY PLANT ENGINEERING PERSONNEL HAVE BEEN TRAINED TO USE TRACE-DIRECT. AT PRESENT, SCORES MORE ARE SCHEDULED FOR TRACE-DIRECT TRAINING.

WE BELIEVE THAT THE USE OF TRACE BY THESE FIRMS IS INDICATIVE OF THE LEVEL OF ACCEPTABILITY AND GENUINE BENEFITS OFFERED BY THE PROGRAM. WE ALSO BELIEVE THAT IT SHOWS IT TO BE VIABLE TOOL IN HELPING TO PREPARE ACCURATE ENERGY ANLYSIS.

TO GIVE YOU A BETTER UNDERSTANDING OF ENERGY ANALYSIS, WE'RE GOING TO OUTLINE FOR YOU THE INFORMATION NECESSARY TO UTILIZE THE PROGRAM, WE'RE THEN GOING TO SHOW YOU HOW TO INPUT IT INTO THE INPUT MANUAL, AND WE'RE GOING TO SHOW YOU THE ACTUAL RESULTS OF THE TRACE RUN ON THE SAMPLE PROBLEM.

(CONTINUE THE WORKSHOP UTILIZING THE ATTACHED WORKSHOP MATERIAL.)

APPENDIX

EXAMPLES OF COMPUTER ASSISTED ENERGY ANALYSIS

This section contains two summary reports describing the results of two computer assisted energy analysis projects, one carried out by the University of Texas at Austin and the other by Texas A & M University. These reports are included as examples of specific research applications of the procedures described in the previous sections.

IMPROVED OPERATION AND CONTROL CAN CONSERVE ENERGY IN AN EXISTING OFFICE BUILDING: A CASE STUDY

By: J. W. Jones,
J. R. Adams &
T. N. Carnes

ABSTRACT:

A study of an existing office building with particularly high energy consumption was undertaken to evaluate possible opportunities for energy conservation. This analysis was carried out in two steps: First, examining building energy requirements in detail and identifying the most promising opportunity for conservation and second, evaluating the potential impact of the various possible conservation measures. A computerized model was used to simulate the building and HVAC system operation. The model was checked by simulating the existing operating system and comparing the results with measured energy consumption. The simulation was then modified to reflect possible control and operational changes expected to reduce energy consumption and re-run. Results indicated savings of as much as 30% were possible with relatively minor modification and modest investment. The study also indicated that operation and control flexibility could contribute significantly to building energy conservation. As a result of this study, a number of the proposed modifications are presently being implemented.

INTRODUCTION:

Energy costs for office buildings have been increasing at an alarming rate. Building owner experience reports (1) indicate that the average expenditure for energy increased by 50% from 1972 to 1974. With the additional increases of the past year many building owners are faced with utility bills double those of just three years ago. This cost increase

is beginning to generate a serious concern for energy efficiency in building design and operation which has not previously existed. For many years, it was cheaper (in an economic sense) to waste energy than to conserve it. First, cost and comfort were the only design considerations given serious attention. The dramatic rise in energy cost and prospects of governmental intervention through new energy motivated building codes and standards are changing this. Energy efficiency are now becoming a very real concern.

Although there are several relatively complete methods for predicting energy consumption as a function of various building or environmental system parameters, they have not yet been widely applied and there is relatively little specific information available on the potential for energy conservation in many areas of the U.S. However, conservation offers both the best and most immediate opportunity for building owners/operators to minimize the adverse effects of increased energy costs or energy shortages. Therefore, a study was undertaken to carefully assess the potential for energy conservation in an office building in Austin, Texas (2).

The building examined was a high rise office structure of eleven stories with 390,000 ft^2 of conditioned space, Fig. 1. Possible architectural changes were considered in this analysis (changes in glazing and window shading) but the major opportunities for conservation were found in the operation and control of the HVAC system.

METHOD OF ANALYSIS:

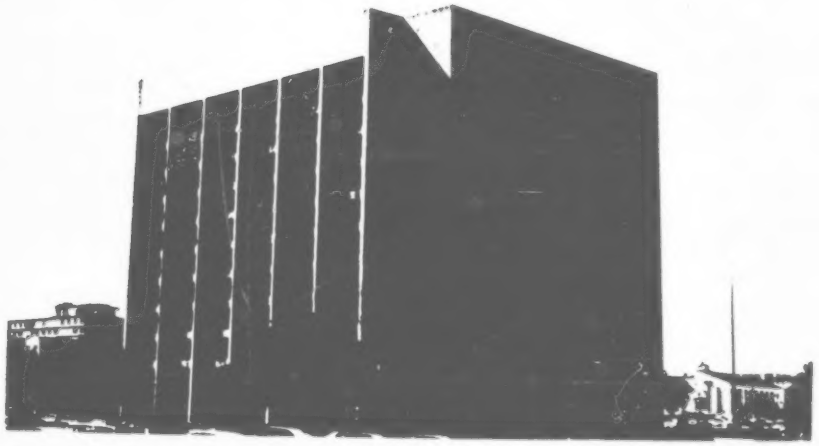
For the purposes of this analysis the energy used in an office building was divided into two categories:

(1) Direct energy used for lighting, office equipment, vertical transportation and miscellaneous uses.

(2) Energy used for heating, ventilating and air conditioning (HVAC)

Figure 1

STEPHEN F. AUSTIN BUILDING, AUSTIN, TEXAS



D.RECT ENERGY USE:

Typically, about 30% to 50% of the energy used falls into the direct use category, while the remainder is used by the HVAC system. Direct energy consumption can be evaluated by means of an energy"audit" which determines the energy requirements of installed lighting and equipment as influenced by building use, occupancy and operating schedules. The use and operating schedules may be unknown for a new building project and it may be necessary to estimate them on the basis of past experience with similar buildings. In the present study these factors were directly determinable from the occupancy and operating history of the existing building. The results of the energy audit for electric energy consumption in the building are presented in Table 1. The direct use of natural gas was minimal, approximately 10 mcf on a typical work day. As indicated in the table, the electrical consumption is split between direct and HVAC auxiliary uses.

HVAC ENERGY REQUIREMENTS:

Several steps of analysis are required to evaluate the amount and distribution of energy used by the HVAC system. The heating or cooling loads must first be calculated. These loads depend on weather conditions, building physical characteristics and internal heat gains. The distribution systems must also be examined to determine how much heating and cooling must be produced to meet the space loads and to condition ventilation air. Finally, the efficiencies of the primary equipment, such as chillers and boilers must be considered.

SPACE HEATING AND COOLING LOADS:

The space heating and cooling loads are a result of:

(a) The internally generated heat from lights, equipment and people.

(b) The heat exchange between the building and its external environment due to temperature differences, solar radiation and infiltration.

TOTAL MONTHLY ELECTRIC ENERGY CONSUMPTION FOR

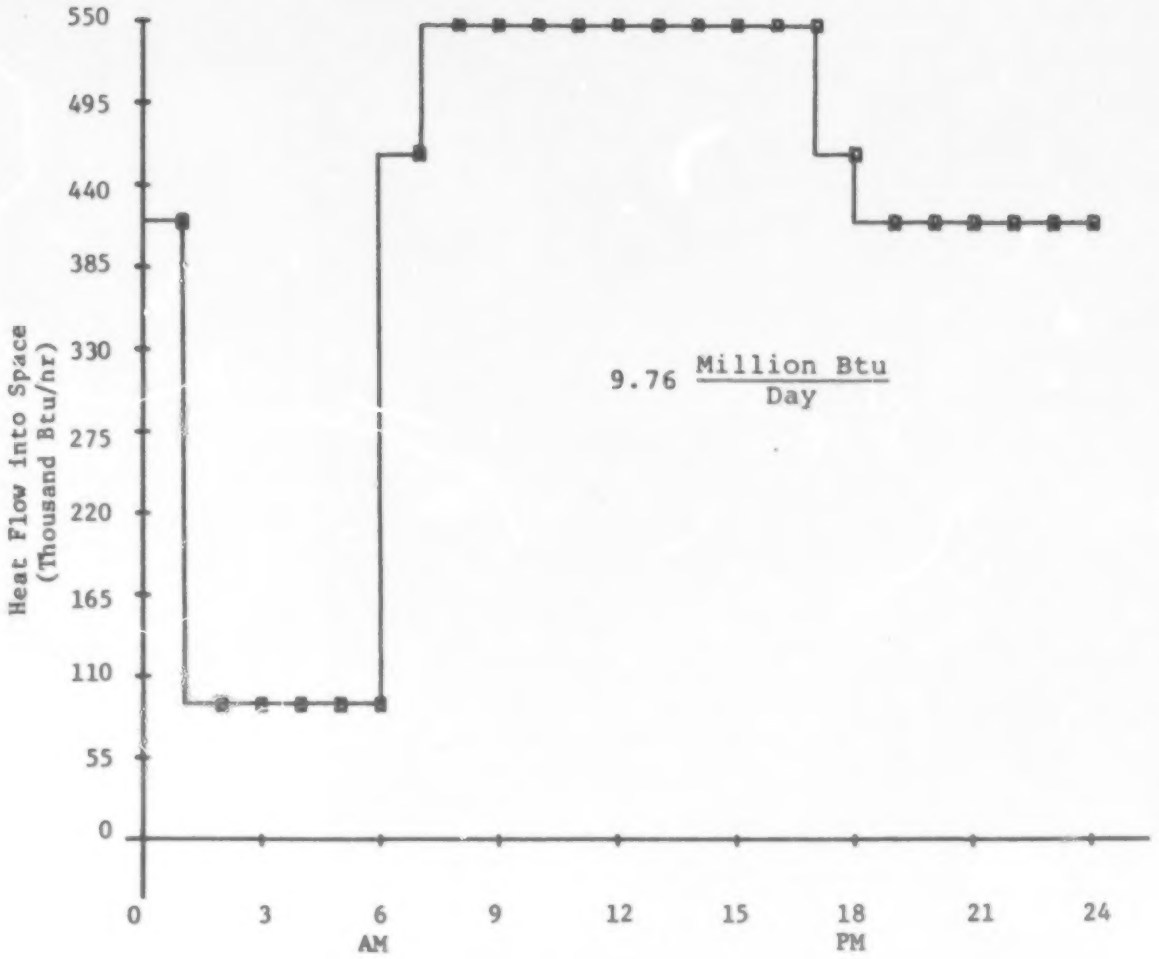
MONTH WITH 22 WORKDAYS AND 8 WEEKEND DAYS

	kwh	Percent of Total Usage
Lights	463,440	42.4
Office and Kitchen Equipment	27,200	2.5
Elevators	16,320	1.5
Miscellaneous Equipment	14,800	1.3
TOTAL MONTHLY DIRECT USAGE	521,760	47.7%
Heating System Auxiliaries	29,700	2.7
Cooling System Auxiliaries	105,300	9.6
Cooling Tower Fans (3)	82,050	7.5
Supply and Exhaust Fans	27,300	2.5
Outside Air-Handling Units (4)	307,200	28.1
TOTAL MONTHLY HVAC USAGE	571,950	52.3%
TOTAL MONTHLY USAGE	1,093,710	100%

The internal generated hearing loads were determined by the energy audit procedures mentioned previously. As is typical of most large office buildings, these internal loads are the primary source of heat as is indicated by the typical daily profile shown in Figure 2. The problem in this particular building is aggravated by the lack of individual light switching and a janitorial schedule that runs from 5:00 p.m. to 1:00 a.m. The majority of the lights remained on throughout this period proir to the initiation of the study.

A computer program, the National Bureau of Standards Load Determination Program, NBSLD, (3) was used to evaluate the transmission and solar loads. NBSLD is a Fortran program with the capability of determining the dynamic heating and cooling requirements of a building. All modes of heat transfer are considered. Measured climatic data and use and operating schedules are used by the program to calculate hour by hour loads for each zone. NBSLD can operate in either of two modes. First, the space load may be calculated by an energy balance with the temperature of the room set at a specified level. The result obtained is then the amount of energy to be input or extracted to hold the room air temperature at the prescribed level. The second mode, using a prescribed heating or cooling capacity, specific upper and lower limits for temperature set points and the weather data input will calculate the variation in energy requirement hour by hour allowing the space temperature to vary within the prescribed limits or exceed the limits if the system capacity is not sufficient. NBSLD requires considerable input data. However, from a set of building construction drawings, handbook values for properties of building materials, and a copy of the engineering manual for the program, the data can be assembled in a reasonable time. The program is also rather lengthy in terms of computer core requirements. But computational time

Figure 2: Internal Load Profile



has been, in our experience, reasonable if the number of zones to be calculated are kept to a minimum. In the present analysis this was accomplished by assuming the building consisted of four perimeter zones and one interior zone per floor. The NBSLD computer program has been used successfully and very effectively by a number of organizations to analyze the heating and cooling loads for a variety of building structures.

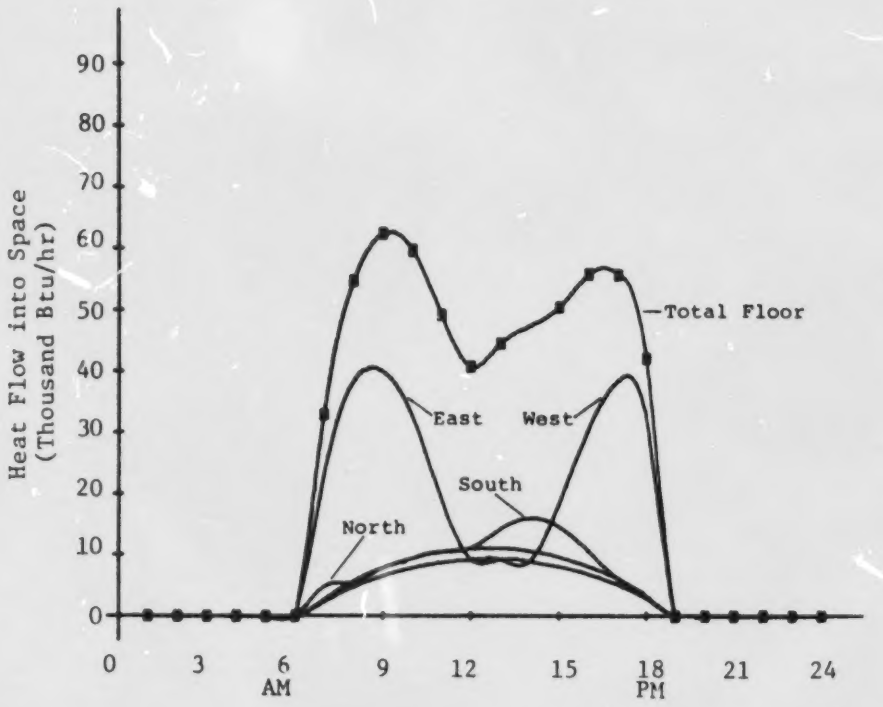
Calculated solar loads for a typical floor for the summer and winter design conditions are shown in Figure 3. It should be noted that the maximum solar loading occurs in the winter rather than the summer at the building's 30^0 N latitude location. The building is 18° from a true north south orientation which accounts for the assemitry of the loads on the east and west zones and contributes to the extremely high "south" zone peak in the winter.

The calculated hourly combined solar and transmission loads for the summer and winter design days are shown in Figure 4. It is of interest to compare these skin loads with the total 9.76 million Btu per day internal load. Hourly profiles for these days which combine both internal and skin loads are shown in Figure 5 for both a typical workday and weekend day. The differences are indicative of the absence of internal load on the weekend. Monthly summaries of daily space heating and cooling loads for the months of August and January are presented in Figure 6.

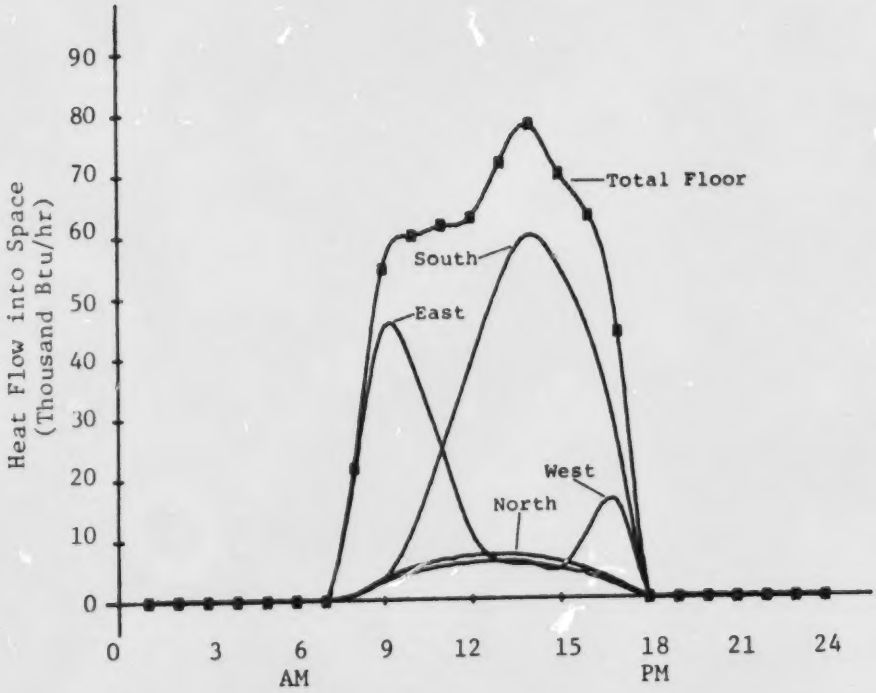
HVAC SYSTEM SIMULATION:

It is important to realize that tye system energy requirements for heating and cooling are not equal to the sum of the building zone heating and cooling loads. The operating characteristics of the system and the efficiencies of its components have a very significant influence on the energy consumption of a building. Thus, the system simulation is an essential element in any energy analysis procedure. It is the link which relates zone heating and cooling loads to the actual energy cost, and to the dollar cost of operating a building.

FIGURE 3: DAILY SOLAR LOAD PROFILES

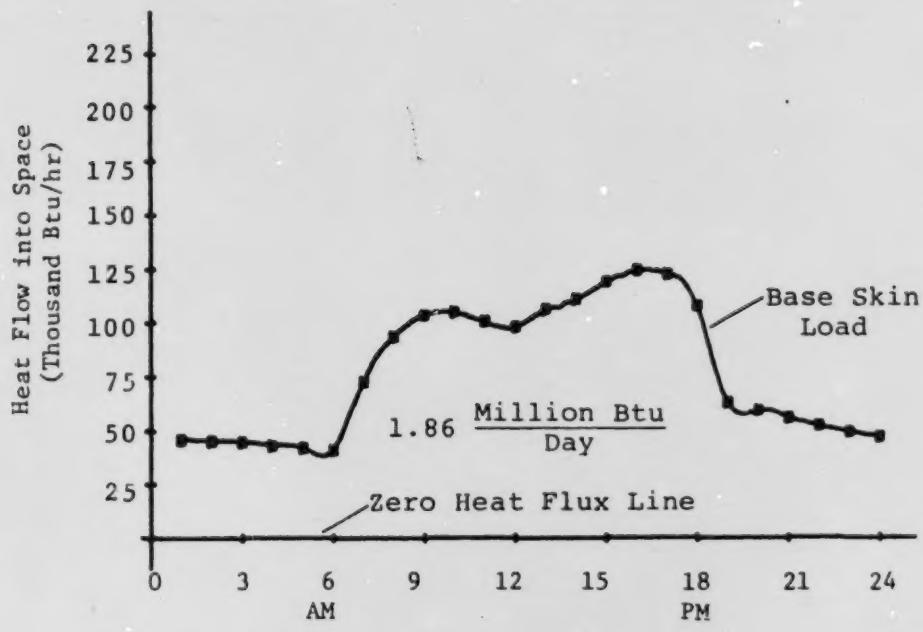


SUMMER BASE CASE

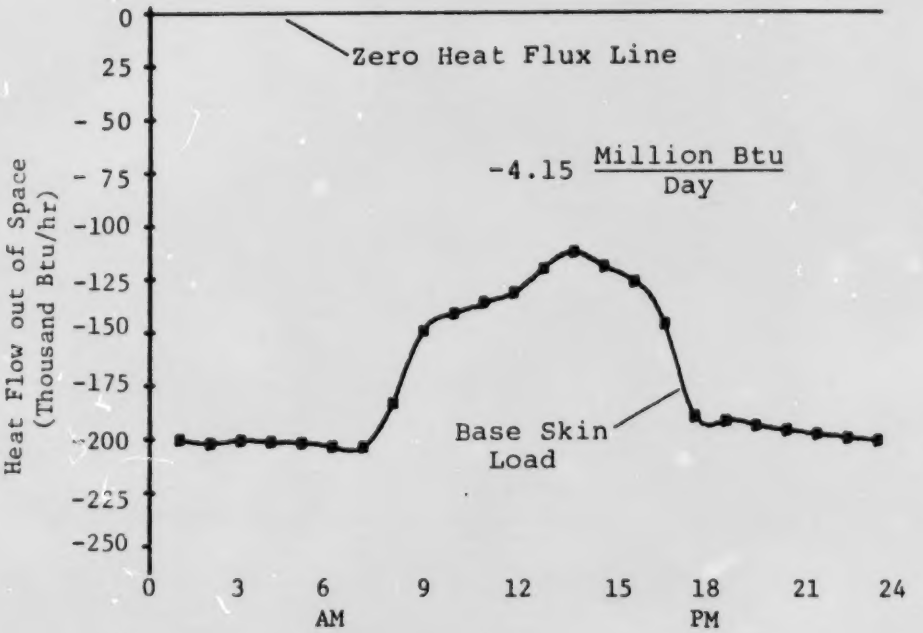


WINTER BASE CASE

FIGURE 4: COMBINED TRANSMISSION AND SOLAR LOADS

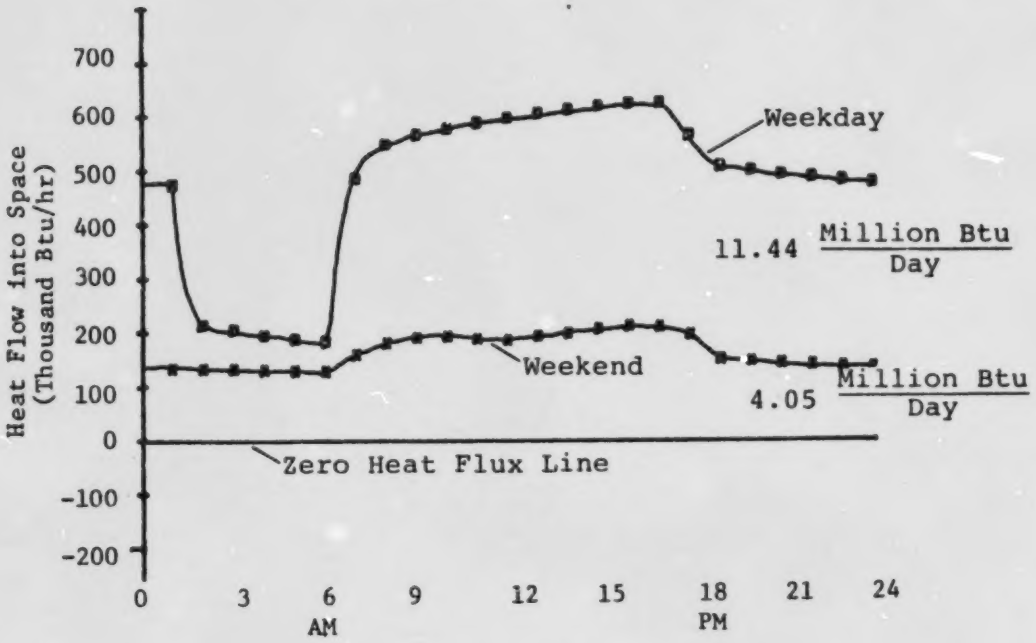


SUMMER BASE CASE

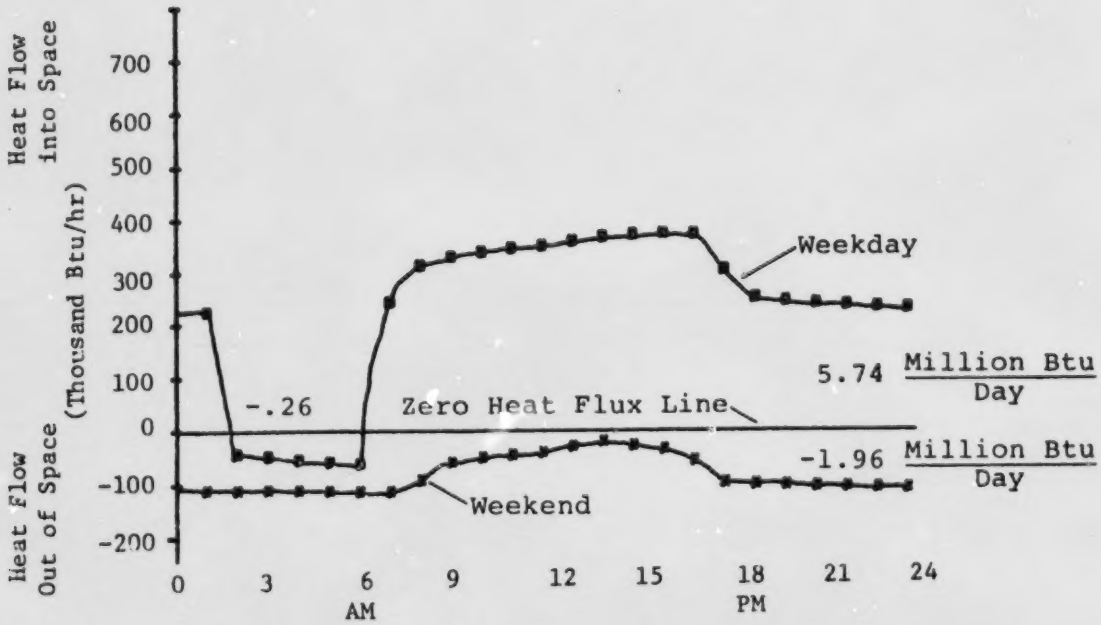


WINTER BASE CASE

Figure 5: DAILY SPACE LOAD PROFILES



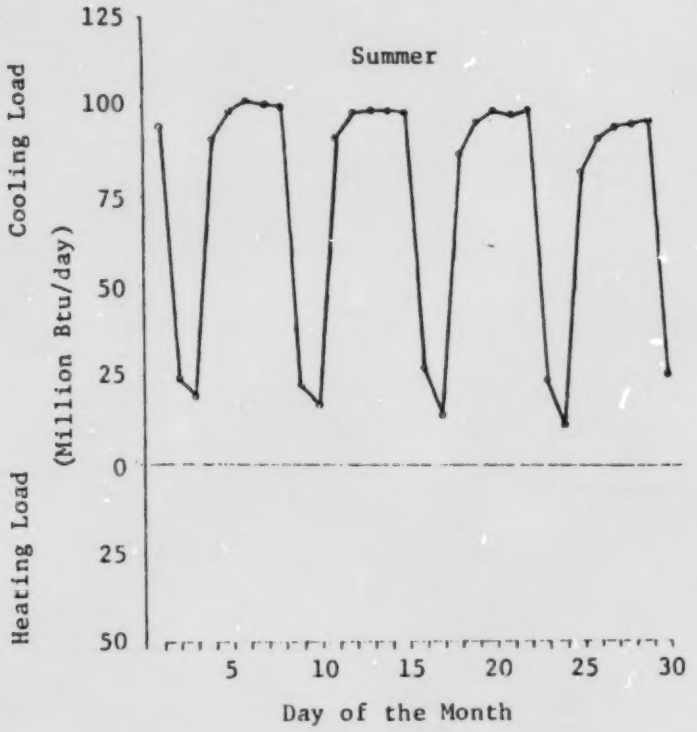
SUMMER BASE CASE

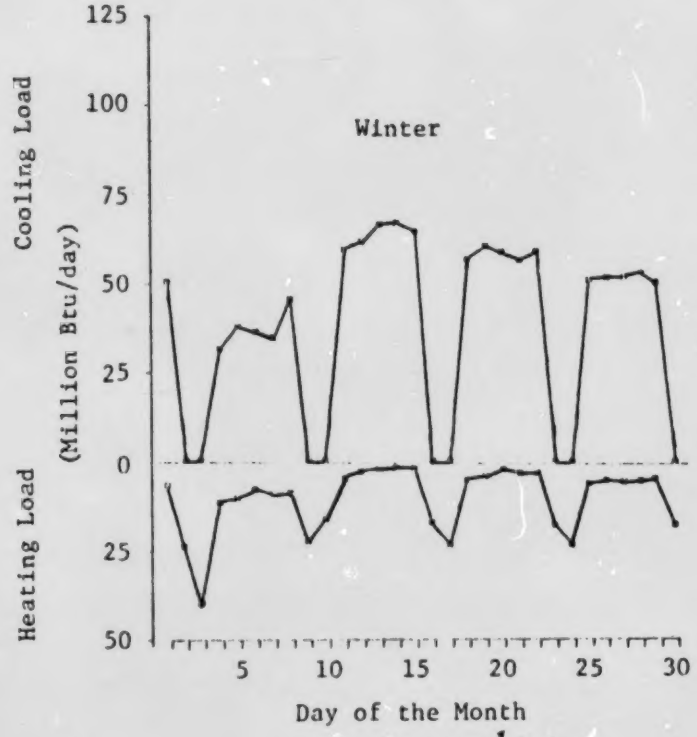


WINTER BASE CASE

Figure 6

DAILY HEATING AND COOLING LOADS ON THE BUILDING





The systems simulation is a composite of subroutines which deal with the specific control and equipment components of a particular HVAC system. Because of the wide diversity of systems in use, it must be tailored to the particular system being analyzed. A general system simulation program may be constructed of a number of component simulation subroutines. The subroutines can be combined in a variety of ways to evaluate the operating characteristics of many different systems. The intent of the simulations is to predict the energy requirements of a HVAC system at a condition where all energy and flow input variables balance, all state equations for working substances are satisfied, and the performance characteristics of each component are described. In their present state of development the simulation procedures used are dynamic only in an incremental sense. That is, they do not account for the short term cycling of a component or any thermal mass of equipment but run an hour by hour sequence of steady state calculations. Operating conditions are assumed constant for a particular time interval and then are changed incrementally to the conditions which exist in the next time interval. Further development will be required before truly dynamic system simulation programs capable of detailed description of control action are available. However, in terms of integrated building loads, the relatively large thermal mass of a building thends to mask the more rapid response of its HVAC system. Therefore, the assumption of incremental variations in system operation provides a reasonable simulation of building energy requirements for present purposes.

The subroutines for system simulation utilized in this analysis are described in references 4 and 5. A specific simulation for the building studied was developed rather than using one of the available general programs. The double duct system studied is a type rather common in existing buildings. It is a system which provides excellent comfort control but is rather inefficient from an energy point of view.

DESCRIPTION OF BUILDING SYSTEM AND CONTROL OPERATION:

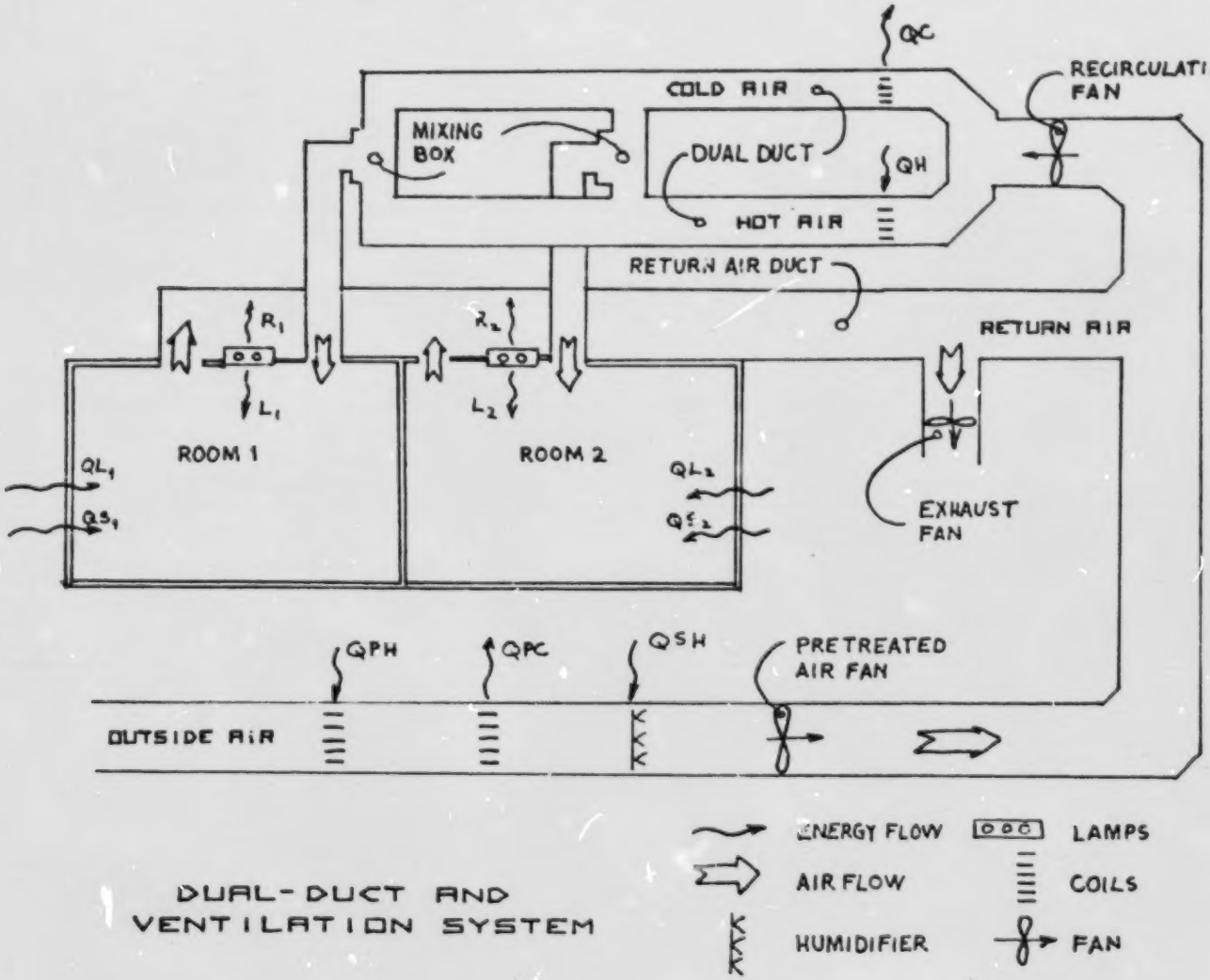
The building studied has a constant volume dual duct air distribution system served by two air handling units on each floor and four air handling units which pre-process the ventilation air. These units are served by hot and chilled water produced by a 1400 ton steam turbine driven centrifugal chiller and 24 million Btuh steam boiler. Figure 7 shows a brief schematic of the dual duct and ventilation air system. Initially the ventilation air handling units were operated continuously, supplying 63,500 cfm 24 hours per day. The ventilation air was preconditioned to 55°F both summer and winter. In the winter mode it was also humidified, using low pressure steam from the boiler, to 85% relative humidity. The ventilation air was then distributed appropriately to the individual floor air handling units, mixed with recirculated air and processed to meet the space loads. Figure 8 indicates the magnitude of the ventilation pre-processing load for typical winter and summer months. During the summer period this load is almost as great as the internal load. Further when considered on a daily basis, it is primarily latent load, much of which occurs during unoccupied hours.

The cold deck of each of the 23 air handling units distributed throughout the building is maintained at a coil discharge temperature of 55° F. The hot deck coil temperature is reset on the basis of outside air temperature. The reset varies the temperature from 96° F at outside temperatures of 40° or below to 80° F for ambient temperatures of 80°F or above. The system provides satisfactory control under varying load conditions but is inherently wasteful of energy.

The primary equipment shown in Figure 9 was then examined to assess any potential for reducing energy consumption. The most obvious candidate for change was the condenser water return. In the original scheme, the condenser water was maintained at a constant 85° F by cycling the fans in the

Figure 7

SCHEMATIC OF DUAL-DUCT AIR DISTRIBUTION SYSTEM



DUAL-DUCT AND VENTILATION SYSTEM

A1-15

Figure 8

DAILY HEATING AND COOLING REQUIRED TO PRECONDITION
OUTSIDE VENTILATION AIR FOR THE BUILDING

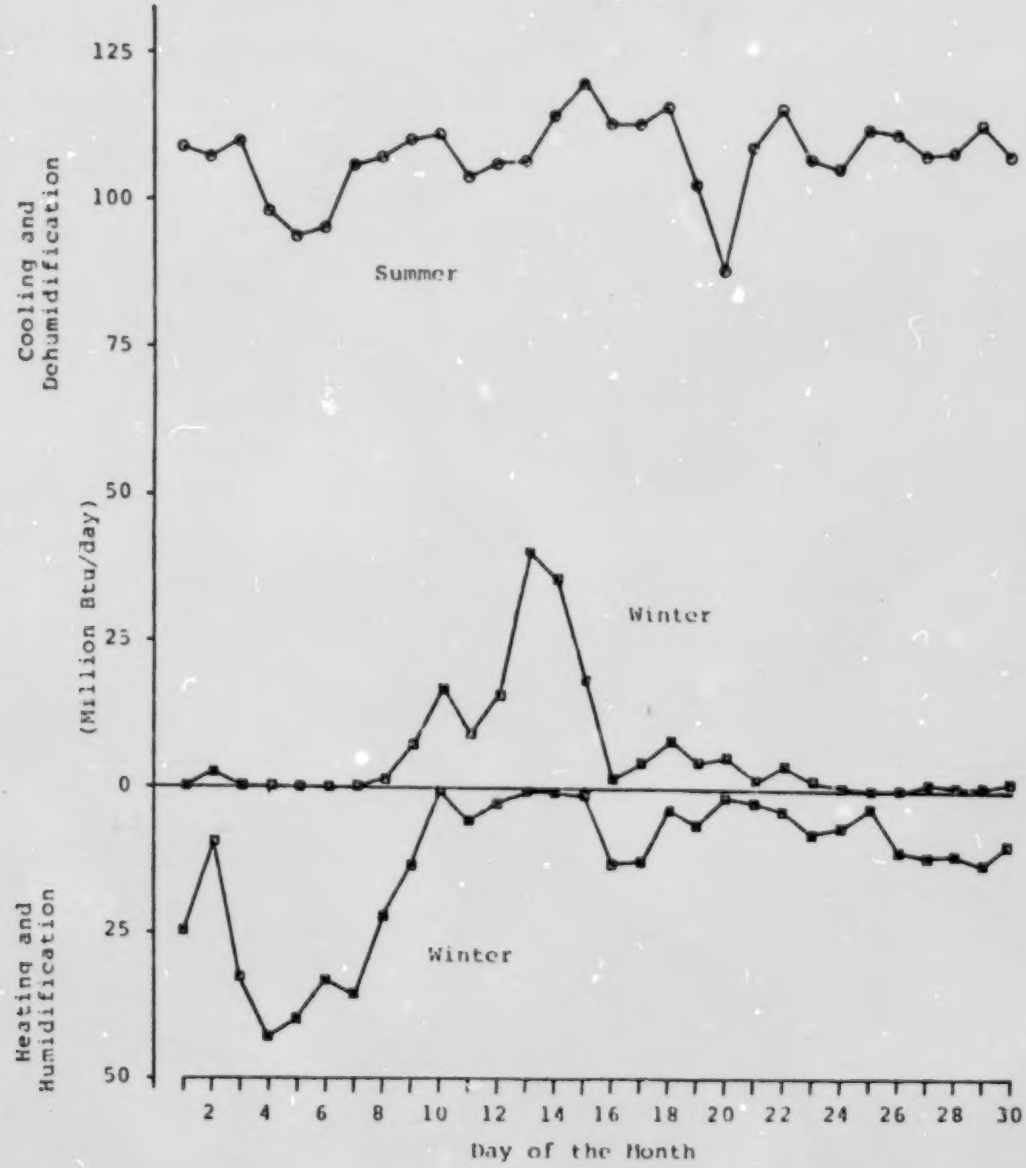


Figure 9

ENERGY FLOWS THROUGH THE HEATING AND COOLING EQUIPMENT

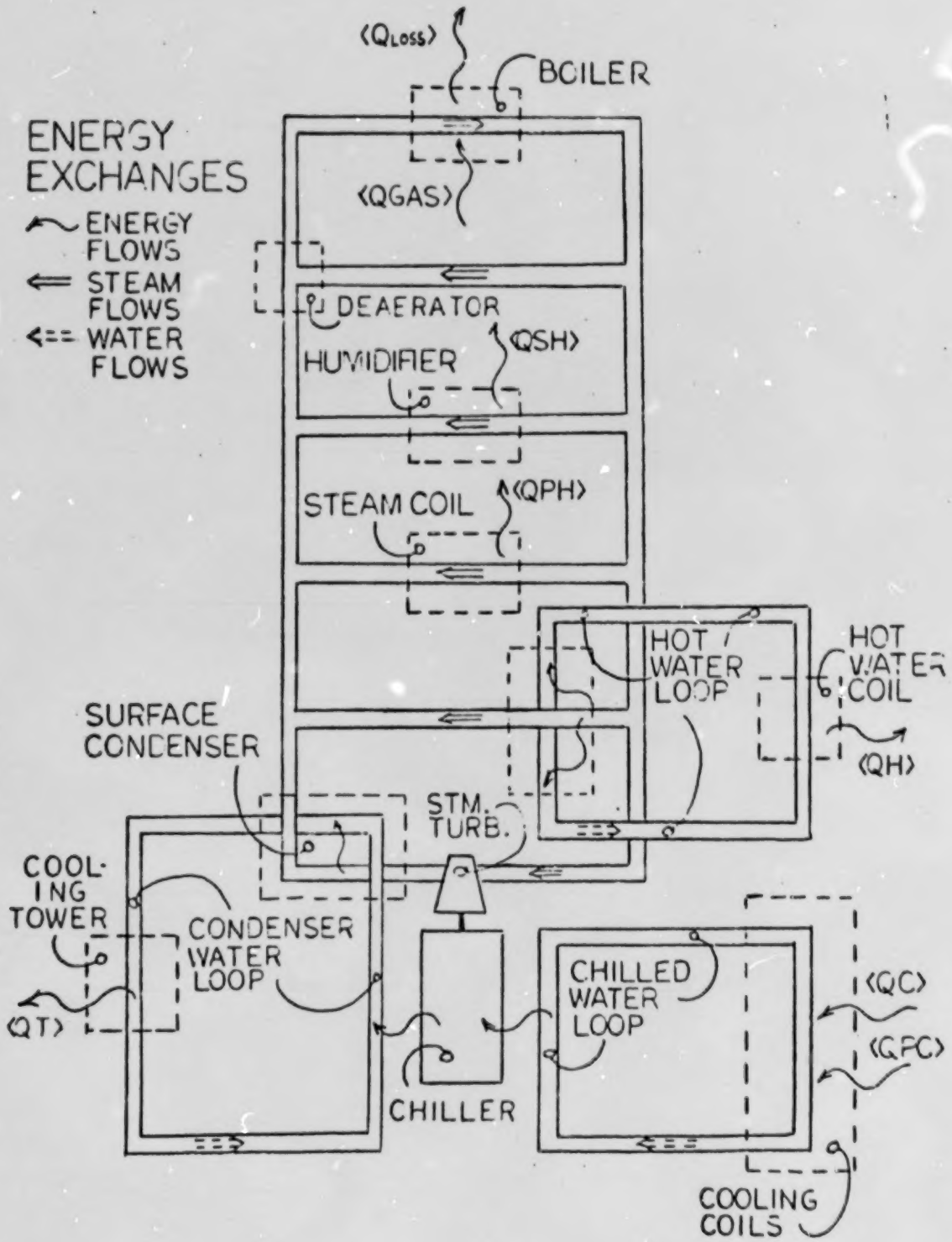
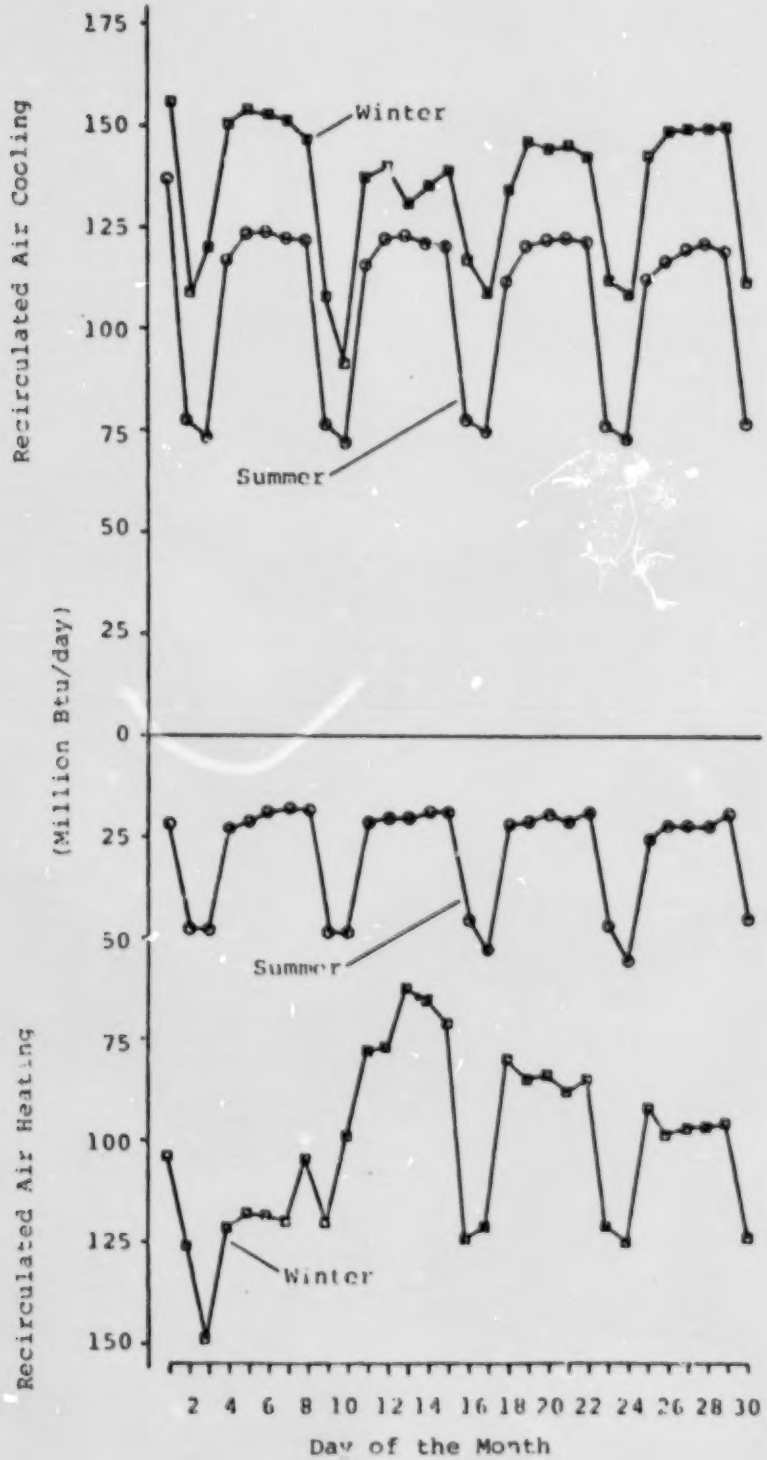


Figure 10

ACTUAL HEATING AND COOLING PRODUCED TO MEET
THE DAILY HEATING AND COOLING LOADS ON THE BUILDING



cooling towers and by bypassing the tower by means of a three way mixing valve if necessary. Initially the primary equipment and auxilaries were being operated continuously.

After developing a system and equipment simulation, the computer analysis was run and checked against daily consumption records which have been maintained since the building's occupancy in February, 1973. Calculated consumption, obtained by means of the load calculations and system simulation were within 15% of measured consumption. Daily consumption calculated for an August and a January month are shown in Figure 10. This figure shows both heating and cooling consumption for both periods and indicates significantly higher consumption for both heating and cooling during the winter month. This is directly attributable to the control scheme originally established for the system.

CONSERVATION OPPORTUNITIES:

Upon the completion of the simulation of the building's initial operation, operation and control features were systematically modified to assess the impact of various conservation schemes. The options specifically considered, individually and in combination are as follows:

1. Modification of the hot deck reset schedule.
2. Reducing the condenser water temperature returned from the cooling tower 5^{o} for each 25% reduction in total load.
3. Shut down of ventilation air handling units during low occupancy of unoccupied periods.
4. Reduced lighting intensity and hours of use.
5. Reduced recirculation air volume to match internal loads reduced by lower lighting level.

CONCLUSIONS:

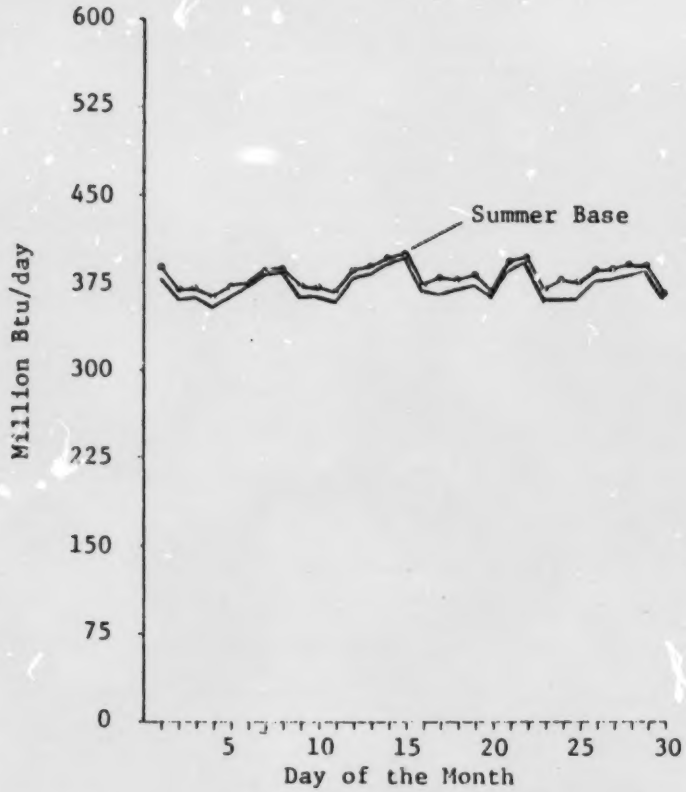
A simple and inexpensive adjustment can be made to the controls on the dual duct system which reset the hot air temperature. As the outside air temperature drops, the hot air temperature is automatically increased to provide

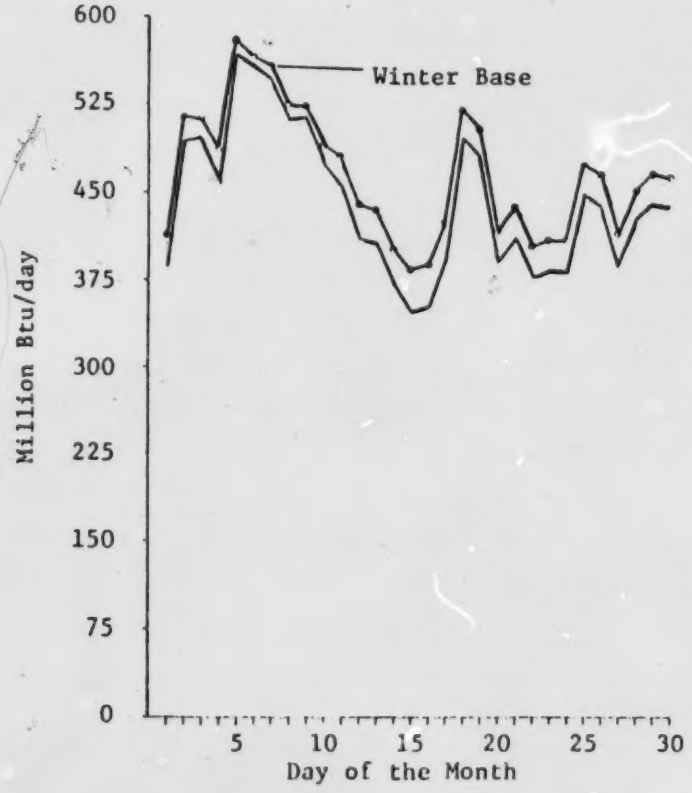
additional heating capacity to meet the increased heating loads on the perimeter zones. These controls are usually initially adjusted to provide enough heating capacity to meet the maximum heating loads which generally occur during unoccupied periods. This amount of heating capacity is not needed during the occupied periods because the internal heat gains from lights tends to offset much of the heat loss. Significant amounts of heating and cooling can be saved by lowering the hot air temperature because the temperature difference between the hot and cold air streams is reduced. Raising the cold air temperature during periods of low cooling loads is also an energy savings possibility. Raising the cold air temperature is doubly helpful if the temperature of the chilled water can also be increased because a higher chilled water temperature improves the performance of the chiller. The controls were originally adjusted to set the hot air temperature at a maximum of 96°F when the outside air temperature dropped to 40°F or lower. In the case shown, the hot deck reset schedule was changed to set the hot air to the maximum when the outside temperature dropped to 30° F or lower. This slight adjustment saved 1.3% summer and 4.6% in the winter. Greater savings can be realized if it is determined that the hot deck reset schedule can be further adjusted and still meet the heating loads on the perimeter zones.

Another modification to the air distribution system which can result in significant energy savings is to reduce the amount of ventilation air. The case illustrated shows the effect of reducing the amount of ventilation air by shutting off the ventilation fans for 14 hours per day when the building is not fully occupied. This reduced the monthly natural gas consumption by 8% in the summer and by 9% in the winter. The savings are larger in the winter because the ventilation fans were shut off during the night time when outside air temperatures are lower. Other methods to decrease the heating and cooling requirements to pretreat the ventilation air,

Figure 11

NATURAL GAS CONSUMPTION WITH
ALTERED HOT DECK RESET SCHEDULE





include reducing the flow rate of outside air and controlling the humidity level of the preconditioned outside air to vary between acceptable levels.

Originally the condenser water temperature was controlled to remain at $85^{o}F$. Allowing this temperature to vary down to $70^{0}F$ greatly improves the efficieny of the chiller thus reducing the steam requirements of the turbine. This change alone reduced the natural gas consumption by 8% in the summer and 11% in the winter. When this change in condenser water temperature control is combined with the two previous modifications to hot deck reset schedule and ventilation air shut schedule the reduction in natural gas consumption is 19% in the summer and 23% in the winter.

Another interesting case which was simulated with the computer model was to reduce the cooling loads on the building by decreasing the lighting wattage by 10% and by cutting off half of the lights during the 9 hours of janitorial work done at night. This reduction in the cooling load decreased the natural gas consumption in the summer by only .6% and increased the consumption by 1.6% during the winter months. This 1.6% increase in the winter months represents a nearly $500.00 increase in the monthly gas bill but the monthly electric bill would be decreased by approximately $4,000.00 at current local prices.

For substantial energy savings to be realized with the dual duct system, when the lighting load is reduced as described above, the amount of air recirculated through the system must also be reduced. A combination case was run with the recirculated air volume reduced 10% and the ventilation air volume was also decreased by 25%. In addition the hot deck reset schedule was changed and the condenser water temperature was allowed to decrease. This combination of 5 modifications to the base case resulted in a natural gas savings of 20.5% in the summer months and 18% in the winter months.

Figure 12

NATURAL GAS CONSUMPTION WITH CHILLER PERFORMANCE IMPROVED
BY REDUCING CONDENSER WATER TEMPERATURE

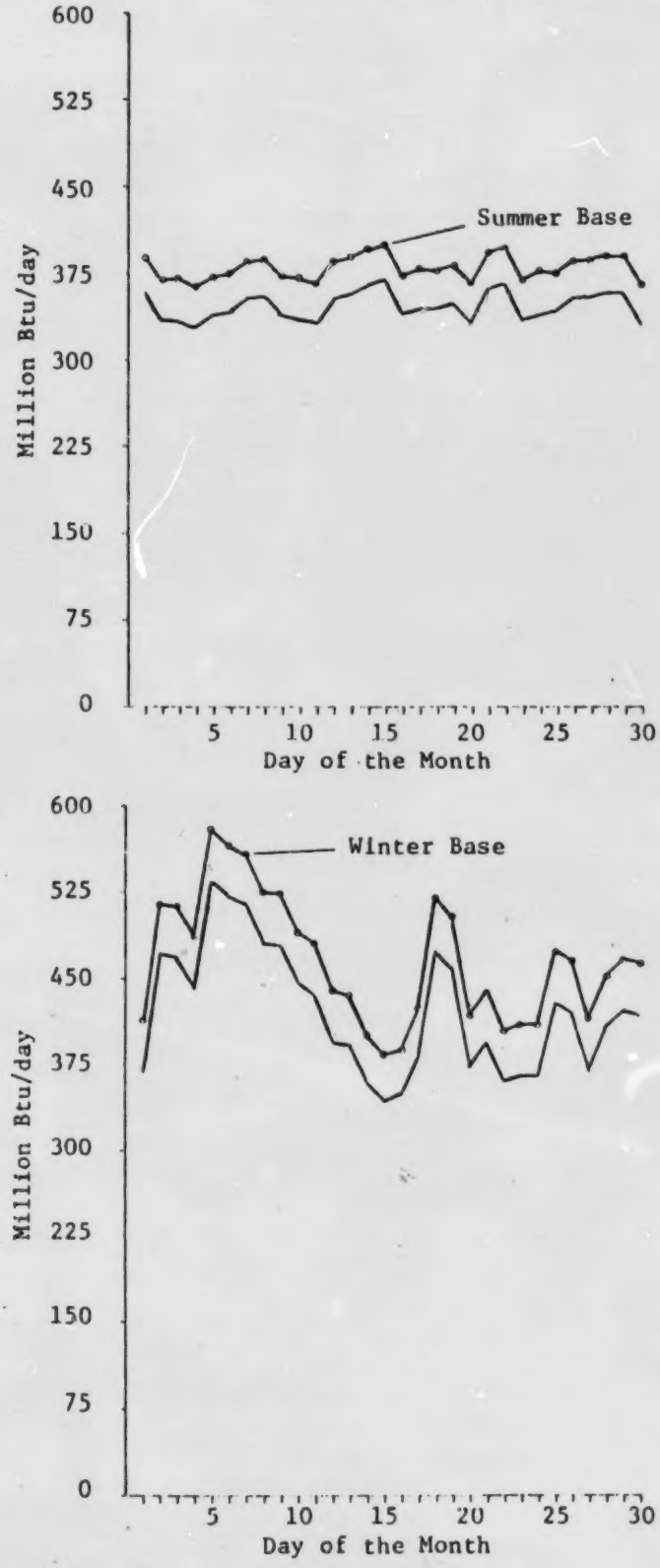
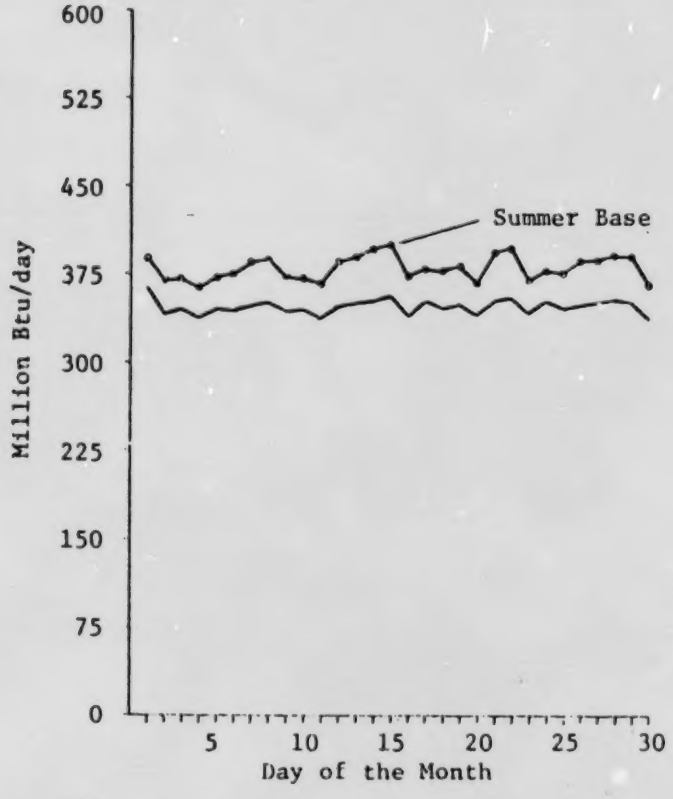


Figure 13

NATURAL GAS CONSUMPTION WITH REDUCED VENTILATION AIR



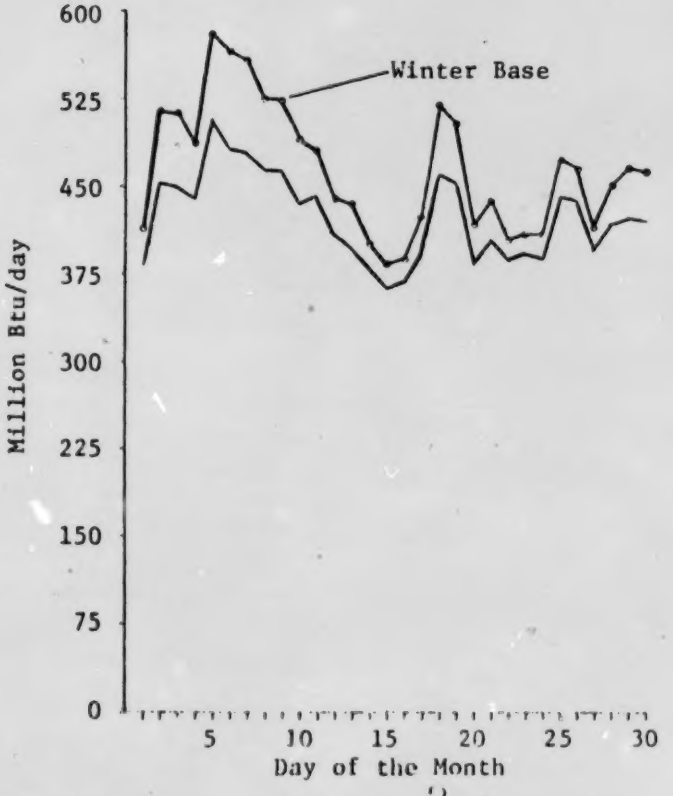


Figure 14

NATURAL GAS CONSUMPTION WITH A COMBINATION
OF THE THREE PRECEDING MODIFICATIONS

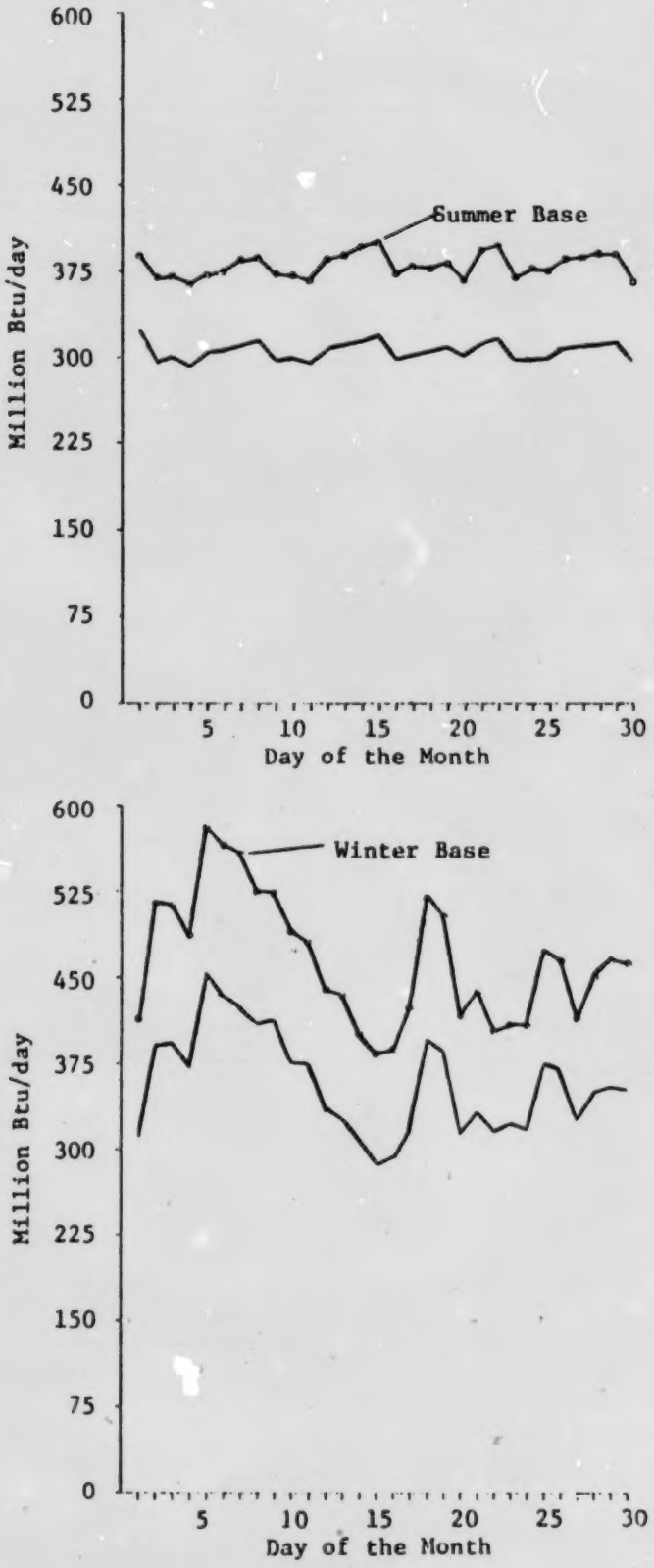
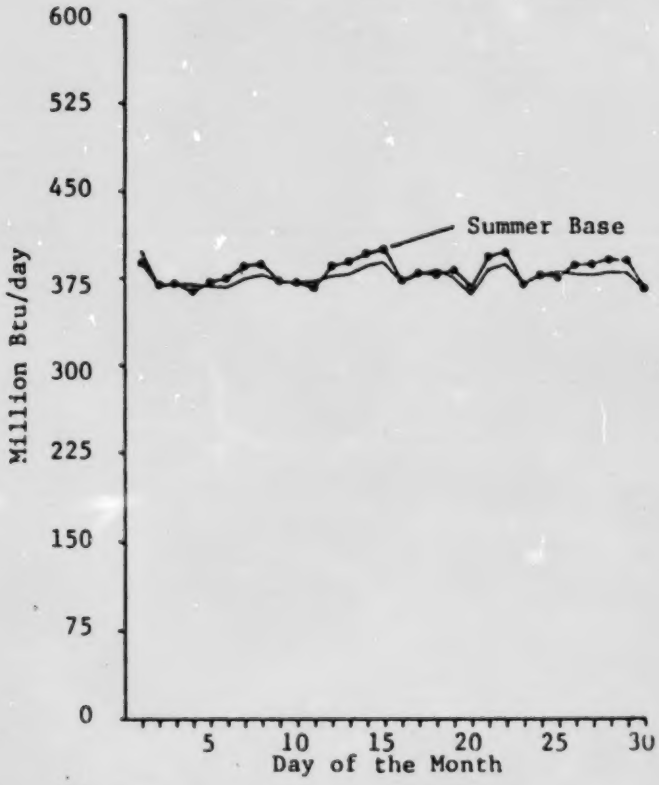


Figure 15

NATURAL GAS CONSUMPTION WITH COOLING LOADS REDUCED
BY DECREASING LIGHTING WATTAGE AND USAGE



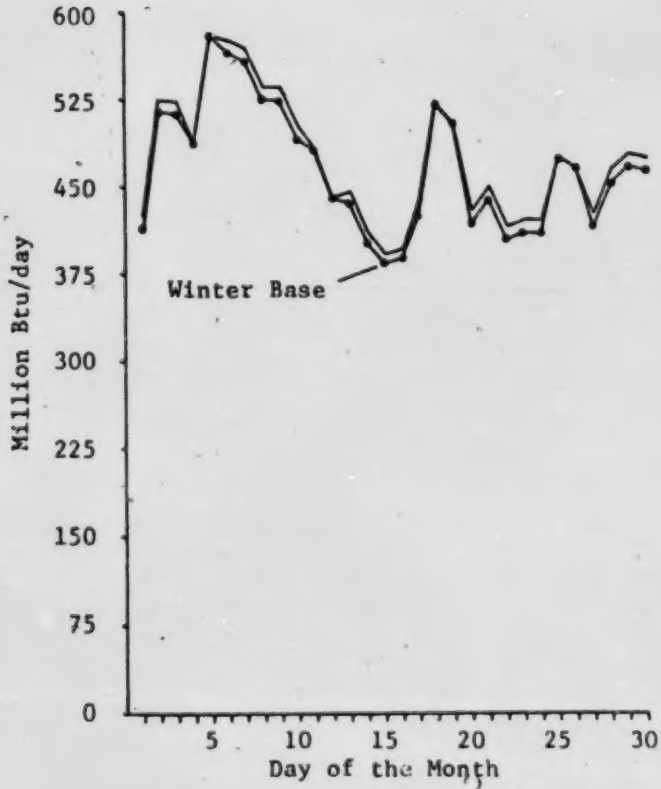
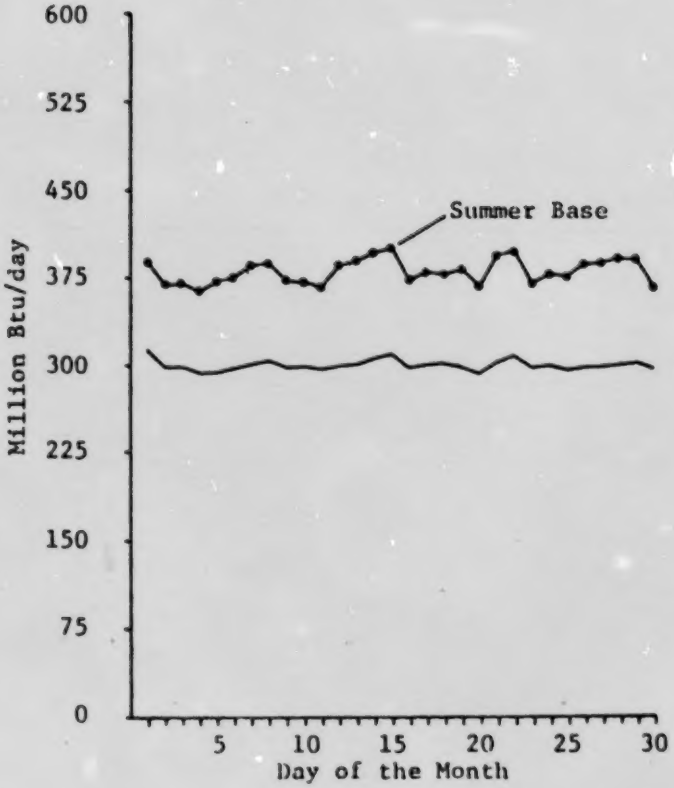
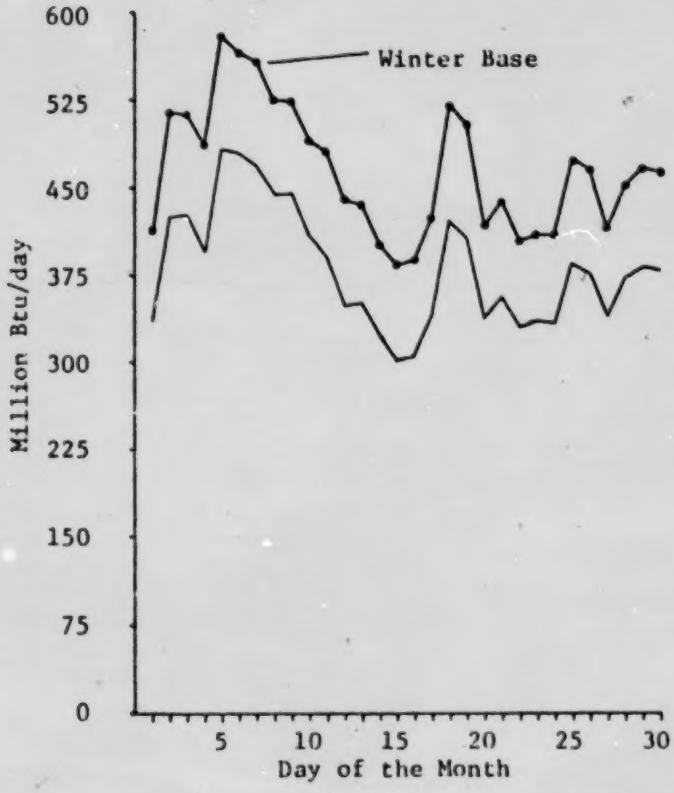


Figure 16

NATURAL GAS CONSUMPTION WITH A COMBINATION OF FIVE MODIFICATIONS TO BASE CASE





ENERGY AUDIT: A CASE STUDY
TEXAS DEPARTMENT OF CORRECTIONS
SYSTEM ADMINISTRATION BUILDING

By: S.A. ANDERSON

The purpose of the reported research project was to identify energy conservation practices that should result in the greatest financial savings in building utility costs for the Texas Department of Corrections (TDC) System Administration Building without sacrificing building utility service or building-user comfort.

The scope of the study and resulting recommendations were limited to and concerned with only those modifications to the existing building and to the building's environmental control system that can be justified economically. Extensive reconstruction of either the air distribution system or the central plant system was not considered. The computer room in the building has an independent air conditioning system capable of handling the heat load generated by the computer equipment. For the purpose of analyzing the central air conditioning system, the computer room was treated as an office space. Energy consumption or potential savings associated with the operation of this secondary cooling system were not considered.

TDC has requested funds from the Texas legislature to implement all suggested changes. The results of this effort were jointly generated by Texas A & M University and TDC personnel.

Methodology for the Study:

The energy audit was a two part study. The first part involved gathering data to establish an "as in use" or "base line" energy comsomption level and resulting operating cost. In this phase, each room in the administration building was surveyed. Lighting levels (in foot candles), and equipment electrical consumption rates, together with occupant usage and other pertinent data, were determined and recorded on an hourly basis for each zone or space. Because utility bills for the building were not available, zone or space useage schedules and electrical power consumption were used to partially estimate the energy requirements of each building orientation and type of air conditioning system were also gathered.

The second part of the study was the use of a computer simulation to analyze the collected data. The building physical data and the user-space requirements were fed into an extensive two part computer program 1 *, which modeled the space load requirement and then the building air conditioning and heating distribution system. The first part of the computer model calculated the distribution and rental plant system energy requirements on an hourly basis for a one year period. Finally, using central plant system data supplied by the manufacturer, the estimate of amount of energy required by the central heating and chilling plant to satisfy the loads imposed by the distribution system was

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*Numbers in brackets denote bibliography references.

further refined. The major shortcoming of this methodology was that the inefficiencies associated with installation, as they affect either the space load, system load or central plant load, were not accounted for in the computer simulation.

Building Description and Usage:

The Texas Department of Corrections System administration building is probably one of the State's most efficiently designed buildings. This three story, rectangular building (Figure 1) has a major north-south exposure (approximately 7000 sq ft) and a minor east-west exposure (approximately 3286 sq ft). Glass composes approximately 11 percent of the vertical building skin. The remaining portion of the building is classified as heavy masonry or stone construction. In all instances, the glass panels in the building skin are constructed from 2- by 8-ft sections of clear 1/4-in. thick plate glass and are set into jambs that are recessed approximately 6 in.in the wall. These "punched openings" (recessed wall mountings) provide the maximum feasible protection from direct sunlight for all the glass in the wall exposures.

The primary building entrances are composed of two sets of double glass doors separated by a foyer. The primary entrances are located on the north and south sides of the building. The double-door-foyer design allows maximum transmission of indirect sunlight into the building without

FIGURE 1. TEXAS DEPARTMENT of CORRECTIONS SYSTEM ADMINISTRATION BUILDING.

imposing the penalty of high infiltration loads on the adjoining spaces. The other entrances do not use the infiltration-efficient, double-door-foyer arrangement. However, the locations of these entrances are such that infiltration through them should always be minimal.

The building, constructed in 1965, encloses approximately 50,000 sq. ft. of conditioned space and 35,900 sq. ft. of assignable office space. Since the building was completed, the interior arrangement has been altered once to increase the number of private office spaces. Much of the space that was formerly dedicated to storage is now being used for office space. The occupancy level now exceeds the level that was established in the program of requirements. The addition of more sophisticated and larger computer machinery necessitated the addition of three roof-mounted, packaged air conditioning systems (two 7 ½-ton units and one 10-ton unit) to handle the additional computer room loads. Because of an increasing prison population and the resulting increased computer staff demands, the roof-mounted units which are capable of satisfying the computer room latent and sensible space loads are presently operated on demand. The computer room is located on the west side of the top floor.

The system's primary telephone switchboard is located on the ground floor. This facility is occupied 24 hours a day throughout the year by at least one operator, who also serves as receptionist. The computer room zone is generally

occupied a minimum of two 8-hour operating shifts each weekday. It is occupied only part-time on weekends. All other space, which can generally be classified as office space, is typically occupied from 8 a.m. to 5 p.m. The thermostats in the building are single set-point thermostats which were assumed set at 72°F.

Existing Space Loads and Recommended Changes:

The term "space load" as used in this context, reflects the annual summation of the net hourly heating or cooling rate (the rate at which heat enters or leaves or is generated within a space); it consists of latent or sensible components and includes

a. ventilation or infiltration of outdoor air;
b. solar radiation through glass areas in the skin of the building;
c. conduction heat transfer through exterior walls and roofs;
d. conduction heat transfer through interior partition, ceilings, and floors; and
e. heat generation within the space from occupants, lights, and appliances.

During inspection of the building, it was noted that the outside air dampers to the air handling system were closed. Apparently these dampers had been closed over an extended period, implying that the ventilation of outside air through the air handler was small. As the ventilation

design rate was 8350 cfm and the outside dampers were closed, the ventilation requirement of the building occupants apparently was being satisfied by some other mechanism, probably infiltration. Standard engineering practice suggests ventilation requirements of 10 cfm/person or 0.1 cfm/sq ft of building space. These requirements yield ventilation air flow rates of 2150 and 4000 cfm, respectively. For purposes of simulation, an infiltration rate of 1.0 percent of the air changes each - approximately 4000 cfm was used in all space load calculations. The ventilation rate was set to zero.

Solar radiation through the east and west exposures of the building is especially severe during the summer months. To reduce the cooling space load in the exterior zone where high solar radiation loads are encountered, it was recommended that highly reflective (80%), laminant film be applied to the inside window surfaces. When a highly reflective laminant film is applied to the inside window surfaces, the solar performance of the glass-and-film windows has positive and negative aspects. The application of this type of film to a window reduces conduction heat load (for 1/4-in. clear plate glass, U = 1.11; when the film is added, U = 0.83), greatly reduces solar radiation (shading coefficient of 1.0 as compared to 0.24), reduces sunlight glare and, for clear plate glass, strengthens the glass. Unfortunately, the transmission of visible light into the space is also reduced. Laminant

application over certain types of glass can cause the glass to fail. Bonding failures between the glass and laminant have been reported by users of certain films. Although applying more insulation to the building walls was not financially attractive, applying reflective paint as the final coating of the roof was recommended. Generally, less than 3 percent of the connected utility load is lost through the roof. However, because of the ease of roof access and the minimal expense involved, a final coating of reflective, fungus resistant paint (reflectance of 0.26 was recommended when the building is re-roofed.

A detailed computer print out of the measured lighting levels for each room was made. All lighting levels in office spaces were measured at desk top level. Generally, more than one reading was taken in each office. Lighting levels in hallways and general work areas were measured at waist height. If the lighting levels are reduced to the levels recommended by the Federal Energy Administration (FEA) [2], it would be possible to reduce daily electrical power consumption due to lighting from an existing 127.63 kwh (3.23 watts/sq ft) to approximately 81.5 kwh (2.06 watts/sq ft.

Because of associated prohibitive computer cost, no attempt was made to quantitatively determine the magnitudes of the space load components. However, a comparison of the space load magnitudes computed before and after the suggested

space load modifications indicated favorable results for the suggested changes. These magnitudes are 32.819×10^7 Btu heating and 2.1555×10^9 Btu heating and 2.1555×10^9 Btu cooling and 2.6919×10^7 Btu heating and 1.664×10^9 Btu cooling, respectively. In both cases, the building was divided into ten zones: three zones on the top floor, three on the first floor, and four on the ground floor (see Figure 2) In all cases the building was simulated against 1952 weather data.

The Air Distribution Systems and Recommended Changes:

The air distribution system in the TDC administration building is a conventional double duct system that operates continuously. A schematic diagram of this system is shown in Figure 3. In a double duct system, an air handler forces a constant air volume through either a hot water coil (i.e., the "hot deck") or through a cold water coil (i.e., the "cold deck"). The temperature in an individual space is controlled by a thermostat that in turn controls a mixing box, which serves the space where the thermostat is located. The mixing box mixes air from the hot duct and cold duct in varying proportions until the specified temperature is reached. (All thermostat set-point temperatures were assumed to be 72^oF summer, 70^oF winter.) Typically, the temperatures of the two air streams which are held constant, are approximately 85^oF (hot deck) and 56^oF (cold deck) as the air leaves the coils.

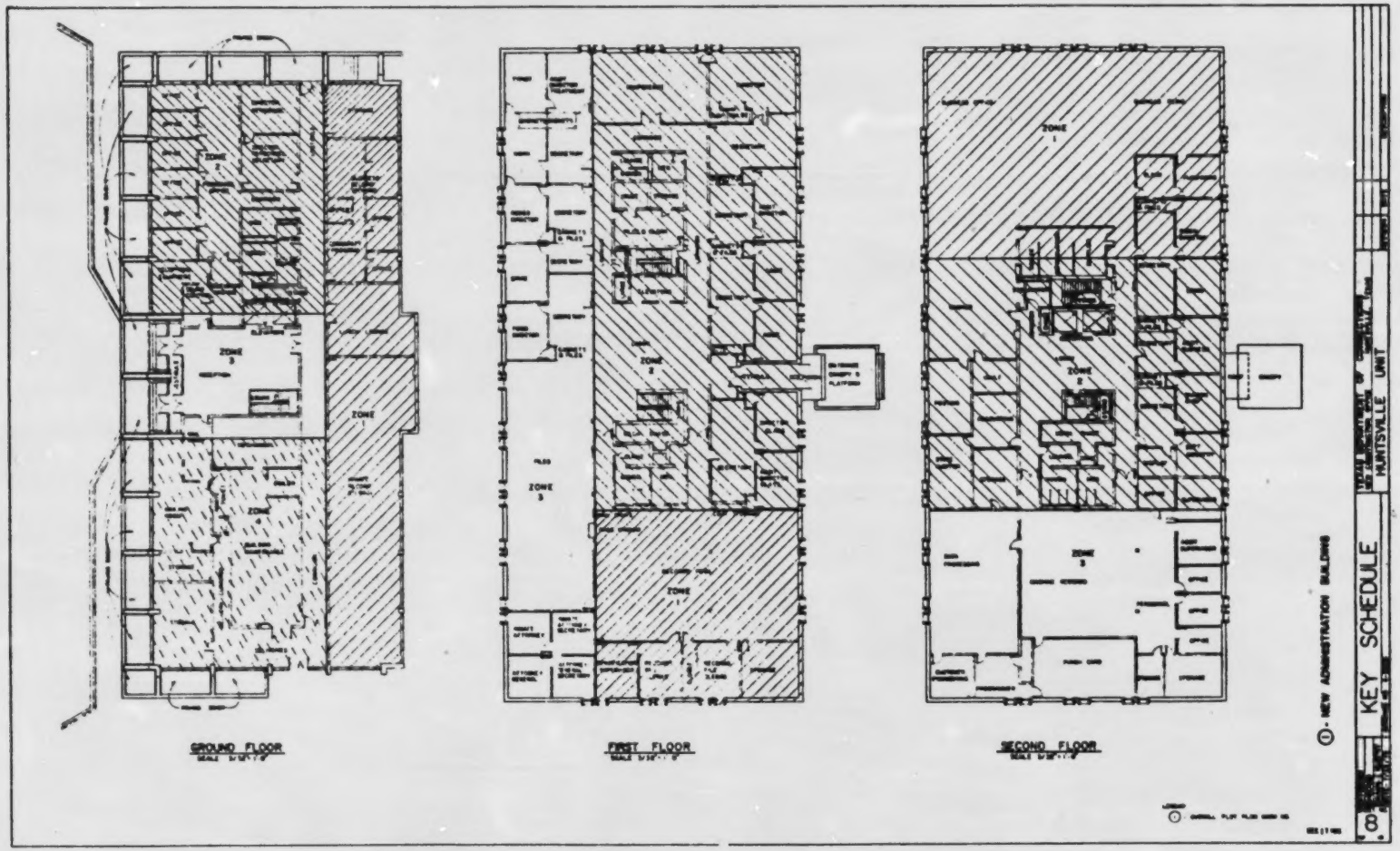


Figure 2: Building Zone Scheme

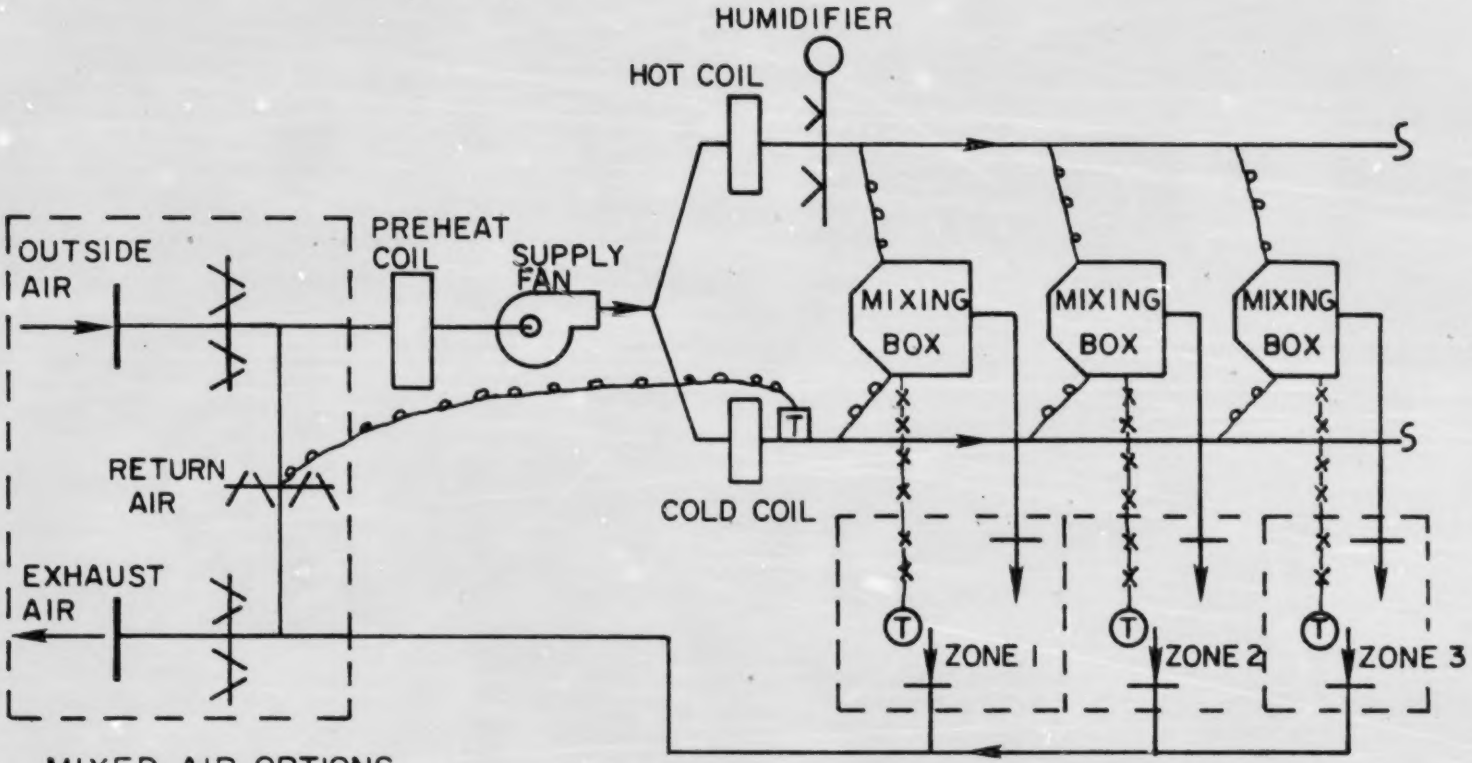


FIGURE 3. DUAL DUCT FAN SYSTEM

A2-11

Typically for an interior zone in the cooling mode of operation, if a thermostat in a space is set at 72°F, the air temperature leaving the mixing box should be approximately 68°F. The air circulates through the space, loses or gains heat in the space and exits the space either through an exhaust system to the outdoors or through a return air system. If a return air fan is present in the return air system, the heat dissipation from the fan increases the return air temperature. The return air may then be totally or partially exhausted from the building, provided the outside air intake dampers are operable. In the TDC administration building, no return air fan exists and the outside make-up air volume was assumed for purposes of calculation to equal the volume of air that was exhausted from within the building.

Several configurations of the system were simulated against the hour-by-hour, zone-by-zone calculated space load output tapes. As indicated earlier, two space loads were generated. One of these simulated the building as it presently exists and the other simulated the building with the following modifications.

a. The building operating schedule was changed from 24 hours per day to 12 hours per day, from 7 a.m. to 7 p.m., on weekdays. The air handlers in the building were shut down at all other times. (Note that all lights in the building follow the same operating schedule. However, the lights, unlike the fan motors, are never totally off.)

b. The reflectance of the roof was changed from 0.768 to 0.260, by painting the roof white.

c. The lighting level was reduced (see Section IV)

d. The air handling system static pressure was reduced from a design value of 6.48 in. of water gauge to 5.8 in. of water gauge. The actual fan system operating pressure is unknown; 6.48 in. of water gauge is the design value.

e. The boiler operating season was reduced. The boiler presently operates from November through March. The annual boiler operating schedule was revised in all cases to reflect a schedule of November through February. This means that space heating through the boiler system is not available and heating requirements, if satisfied, must be met by some alternate means, such as lights or occupants.

f. In all cases, zone set-points were 72°F summer, 70°F winter,. Relative humidity was allowed to vary between 50 and 70 percent. Fixed coil temperatures were 120°F and 55°F for the hot and cold decks, respectively.

Other variances between the systems that were simulated are discussed later.

The air distribution systems simulation had two major objectives. The first objective was to examine all changes to the existing system with the aim of determining which were

most financially advisable. The second objective was to consider financially feasible modifications to the air distribution systems, which would result in another type system, different from a conventional double duct system that would be more energy efficient. In the first case (i.e., modification of the conventional double duct system), the changes considered were hot and cold deck temperature reset, incorporating an enthalpy controlled economizer cycle into the air distribution system, and reducing the exhaust air and outside make up air rates from 8350 cfm (per design) to some lower value. In the second case, modification of the existing double duct system to produce a variable volume heating or cooling system was simulated with and without hot and cold deck reset and with and without an economizer cycle.

Financially feasible modifications of the existing double duct system to reduce building energy consumption are related to the addition of hot and cold deck temperature reset capability to the existing system. The hot and cold deck temperature reset capability to the existing system. The hot and cold deck reset capability is added by extensively modifying the environmental system instrument control package. The package continually monitors all thermostat set points, and the lowest and highest set-point temperatures required for cooling and heating, respectively, are identified. The temperatures of the water leaving the chillers, the water

leaving the boiler are then reset to satisfy the minimum chilled water and maximum hot water requirements called for by the controlling hot or cold zone. By resetting the chilled water temperature upward* (normally it leaves the chiller at 45°F) and the boiler water temperature downward (normally it leaves the boiler at 120°F), the amounts of electrical power necessary to drive the chillers and the gas consumed to fire the boiler are reduced. Energy savings, although associated with the space load and air distribution systems, actually result from reduced requirements on the central plant.

The use of the term "economizer cycle" in conjunction with an air conditioning system implies that environmental control system duct work is such that outside air can be inducted into the space for cooling. In the TDC administration building, cooling is required even in the winter, because the heat from lights, equipment and people is not offset by the heat loss through the walls and by infiltration of outside air. As a consequence, the air conditioning system (primarily the fans and chillers) must operate all year. There are times when the outside air total energy content is low enough that outside air can be brought into the building and distributed to the zones through the fan system for space cooling, and the chiller system can be shut down. This capability is referred to as an economizer cycle. As with a hot and cold deck reset capability, the economizer

cycle is controlled by the building instrument package. The outside air conditions are continually monitored and the economizer cycle is activated to various degrees depending on the economizer set-point associated with induction of outside air into the building.

There are two basic control modes associated with operation of the economizer cycle, (1) outside temperature, or (2) enthalpy of the air, "total heat". There are rare conditions when the outside air temperature is low enough so that outside air can be used for space cooling, but the moisture content is such that if the air were inducted into the space, the resulting moisture level would be too high. Consequently, the economizer cycle control on outside air temperature only is not always satisfactory. However, enthalpy control of the economizer cycle is governed by both the outside air dry bulb temperature and the space moisture requirements. The duct work in the TDC administration building, especially the outside air make-up duct work into the mechanical equipment room, would accommodate the installation of an economizer cycle into the air distribution system. Implementation would require additional instrumentation/control capability and possibly the installation of one or more fans in the existing return air duct.

Modification to the existing double duct system to produce a variable volume, double duct hot or cold air distribution system, which would incorporate various hot and and cold deck reset options and economizer cycle options, was

also considered. This system would eliminate the mixing of hot and cold air to produce tempered air that is associated with the conventional double duct system. It would also supply each zone with the magnitude of heating or cooling required to satisfy the thermostat setting. Equation (1), developed from conservation of energy for steady flow

$$\dot{q} = \dot{m}\, h \qquad (1)$$

can be applied to a zone, or space. The variable $\dot{q}$ represents the rate of net heat loss or gain in a space, $\dot{m}$ represents the mass rate of flow that is a product of air density and volume flow rate (cfm) and h is the change in enthalpy of the air as it goes across a coil. The enthalpy change of the air, h, corresponds to an enthalpy change in the chilled water as it goes through a coil. It also reflects directly the temperature of the water entering the coil.

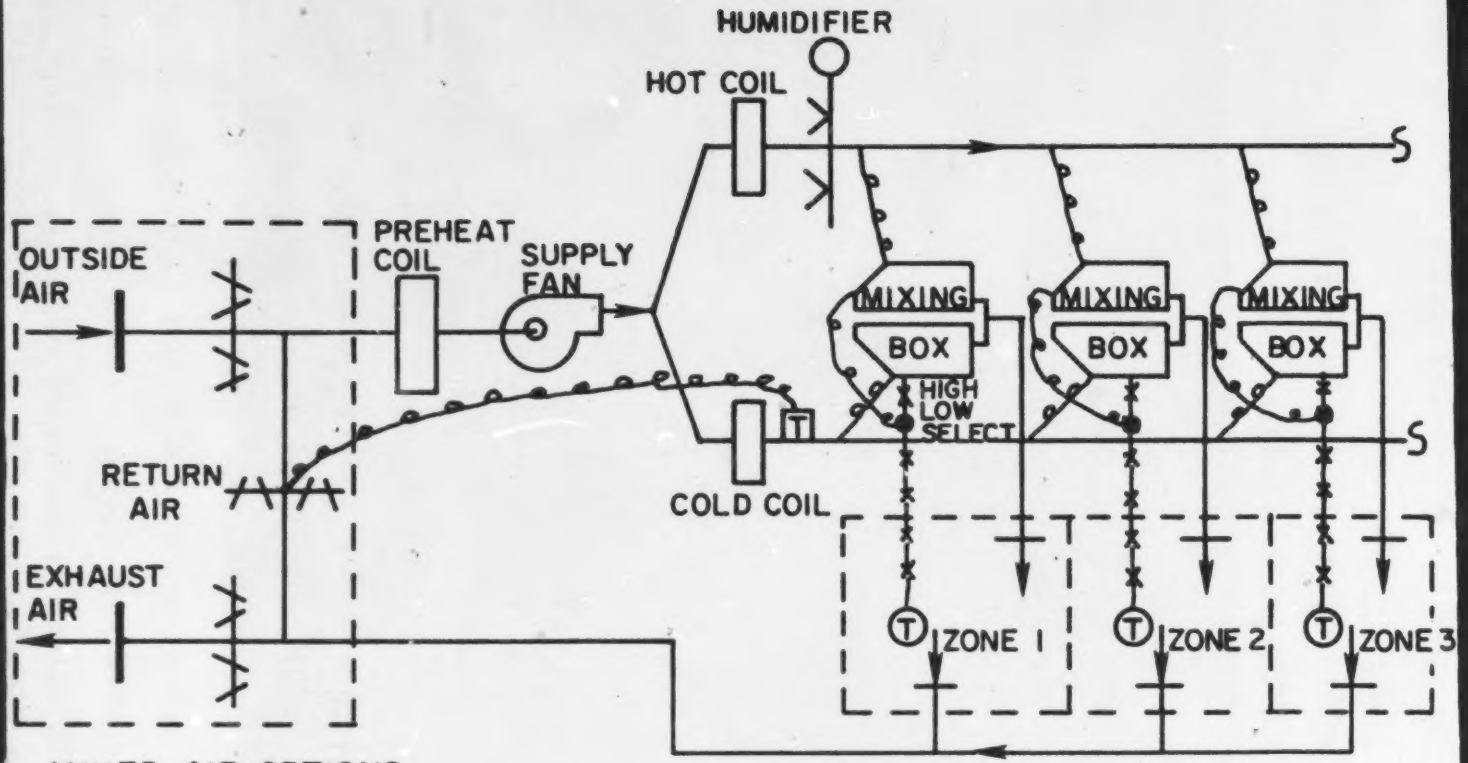
As can be seen from equation (1), for a fixed space load magnitude, numerous combinations of mass flow rate to the zone and enthalpy changes across the coil exist, which will satisfy the space load. If the primary control mode is hot and cold deck reset, then fan horsepower requirements must vary slightly with volume flow rate (cfm) to the zone. Conversely, if the hot and cold deck temperatures will not be reset, (i.e., they will remain constant) then, again, the volume flow (cfm) to the zone must vary, but the variance will be considerably greater in magnitude than with the hot and cold deck reset. Thus, hot and cold deck reset capability reduces the energy that the chillers and boiler consume to satisfy the system load at the great variance and

expenses of fan horsepower. Alternately, fixed hot and cold deck temperatures subordinate the chiller and boiler energy consumption to fan energy requirements.

Until recently, air distribution hardware necessary to convert a conventional double duct system to a double duct, variable volume, heating or cooling system was not readily available. This hardware is now available from many manufacturers, and one has available on the market a variable volume box whose performance is independent of system static pressure. This particular box has a static pressure requirement of 0.1 in. of water. This box does not mix hot and cold air. It is in reality two compact boxes that are independant of each other and are back to back.

Cost data and results reported in this study reflect converting every double duct mixing box in the building to a heating or cooling box by installing new boxes. As an alternate, it was recommended that consideration be given to conversion of the core zone of the building to variable volume cooling only and conversion of the perimeter zones to variable volume, double duct heating or cooling and that possibly kits could be purchased for the existing boxes. Although installation cost data do not reflect those alternates, system performanance should not be appreciably different. The installation cost data presented would be reduced if the core section of the building were supplied with a variable volume cooling capability only or if the existing boxes could be modified.

To take full advantage of the reduced fan horsepower requirements normally associated with a variable volume system, it would be necessary to install additional air-flow-metering control equipment in the existing hot and cold trunk ducts off each air handler. Many failures of variable volume systems have occurred since installation of this type system began a few years ago. These failures have generally been traced to the means associated with control of the air flow. Of the three basic control schemes currently used for control of variable volume systems, only the scheme that involves the use of air-flow-metering stations and duct pressure sensors appears satisfactory. Figure 4 illustrates a typical control scheme that is necessary for satisfactory variable volume system control. Figure 5 indicates the air distribution system. The air-flow-metering station produces a velocity pressure signal that is proportional to duct volume. The output signal from the static pressure sensor is paralleled with the output signal from the flow meter. When the duct pressure sensor (because of high-low select switch) is transmitted to the damper motor on the fan inlet. In normal operation, the output signal from the flow meter controls the damper motor on the fan inlet. Only recently have satisfactory low differential pressure (0 to 1/4 in. of water) transmitters and volume metering devices been available. The volume metering device must have a very low pressure drop across it if the variable volume system is to result in reduced fan horsepower requirements without loss of flow meter accuracy; the velocity pressure transmitter selection is critical. Two



MIXED AIR OPTIONS

1. FIXED DAMPERS
2. ENTHALPY/ TEMP. TYPE ECONOMIZER CYCLE

FIGURE 4. DUAL DUCT, VARIABLE VOLUME HEATING or COOLING SYSTEM

manufacturers have available flow metering stations; one has velocity pressure transmitters, flow metering stations and controllers that, if properly selected and installed, will result in a satisfactory variable volume system that produces desired fan horsepower savings. Instrument selection becomes even more critical when an economizer cycle is incorporated into air distribution system.

Table I summarizes the comparative energy-saving results of the computer effort. Variable volume fan performance was based on the performance normally associated with inlet dampers on the fan*.

Finally, it should be noted that the computer simulation results indicated a maximum volumetric flow rate of 40,126 cfm to satisfy the annual peak heating or cooling load in the building. This volumetric flow rate is based on a set-point temperature of 72°F. According to the mechanical plans of the TDC administration schedule, the mixing boxes were sized as indicated in Table II.

These data, together with the design static pressure increase across the fans (6.48 in. of water), suggest that the mixing boxes are oversized, that the air flow rate exceeds that which is needed, or that both of these factors are present. Air balance data is not available for this building.

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*Selection of variable pitch vane axial replacement fans might be economically justified in this situation. Should TDC want to consider this option, additional computer results can be generated.

TABLE I
SUMMARY OF RESULTS
ANNUAL UTILITY USAGE

I. Existing Double Duct System - Case A

A. Outside air make-up and exhaust through infiltration and ventilation, were assumed to be 8350 cfm or 16.7% of air volume
B. Electrical power consumption 1,584,086.0 kwh
C. Natural gas consumption 27,648.0 Therm*
D. Water consumption 1,075.0 K gal
(Examination of the computer results is suggested for detailed data)
E. Total annual cooling not met** 0.0 MBtu
F. Total annual heating load not met 4,090 MBtu

II. Modified Double Duct System

A. Outside air make-up and exhaust, through combined infiltration and ventilation were assumed to be 8350 cfm or 29.8% of air volume, minimum
B. Options: (Examination of the computer results is suggested for detailed data)

1. Case B
   a. Hot and cold deck reset capability
   b. Enthalpy controlled economizer cycle
   c. Energy usage
      1. 908,858.0 kwh
      2. 1,594.0 Therm
      3. 347.0 K gal
   d. Total annual chilling load not met - 111 MBtu*
   e. Total annual heating load not met - 4,750 MBtu****

2. Case C
   a. Hot and cold deck reset capability
   b. No economizer cycle
   c. Energy usage
      1. 914,913.0 kwh
      2. 690.0 Therm
      3. 332.5 K gal
   d. Total annual chilling load not met - 111 MBtu*
   e. Total annual heating load not met - 969 MBtu****

3. Case D
   a. No hot or cold deck reset capability
   b. Enthalpy controlled economizer cycle
   c. Energy usage
      1. 927,552.0 kwh
      2. 7,940.0 Therm
      3. 411.0 K gal
   d. Total annual chilling load not met - 0.0 MBtu*
   e. Total annual heating load not met - 154,250 MBtu****

*10 Therm = 1000 Cu ft. of gas = MCF = 1 x 10^6 MBtu = 1000 MBtu

**"Loads not met" is the sum of the magnitudes of demand; the equipment is capable of supplying some of this energy.

4. Case E
   a. No hot or cold deck reset capability
   b. No economizer cycle
   c. Energy usage
      1. 937,881.0 kwh
      2. 6,589.0 Therm
      3. 430.0 K gal
   d. Total annual cooling load not met - 0.0 Btu
   e. Total annual heating load not met - 9,69. MBtu****

III. Variable Volume, Double Duct Heating or Cooling System
   A. Outside air make-up and exhaust, through combined infiltration and ventilation, assumed to be 4000 cfm or 10.0% outside air make-up, minimum
   B. Options (See computer results for detailed information)
      1. Case F
         a. Hot and cold deck reset capability
         b. Enthalpy controlled economizer cycle
         c. Energy usage
            1. 903,241.0 kwh
            2. 247.0 Therm
            3. 383.0 K gal
         d. Total annual chilling load not met - 61,470 MBtu***
         e. Total annual heating load not met - 142 MBtu****

      2. Case G
         a. Hot and cold deck reset capability
         b. No economizer cycle
         c. Energy usage
            1. 912,270.0 kwh
            2. 237.0 Therm
            3. 420.0 K gal
         d. Total annual chilling load not met - 62,005 MBtu***
         e. Total annual heating load not met - 26 MBtu****

      3. Case H
         a. No hot or cold deck reset capability
         b. Enthalpy controlled economizer cycle
         c. Energy usage
            1. 887,542.0 kwh
            2. 208.0 Therm
            3. 383.0 K gal
         d. Total annual chilling load met - 30,164 MBtu***
         e. Total annual heating load met - 331 MBtu***

      4. Case I
         a. No hot or cold deck reset capability
         b. No economizer cycle
         c. Energy usage
            1. 895,725.0 kwh
            2. 200.0 Therm
            3. 417.0 K gal
         d. Total annual chilling load not met - 31.796 MBtu***
         e. Total annual heating load not met - 133 MBtu****

The fan horsepower energy requirements, which were calculated in this study (see Computer Results), result from scaling of generalized fan performance data to the maximum volumetric flow rate requirements. The calculations are based on installation of discharge dampers on the existing centrifugal fans. This scaling procedure does not account for reduced system pressure requirements nor does it adequately reflect the fan horsepower requirements associated with reduced system pressure requirements. Thus, it is probable that the fan horsepower energy requirements may be considerably less than that indicated if some form of variable volume system is implemented in the building. Additional energy savings would also be realized if a vane axial, variable pitch or fluid drive fan were installed.

The Central Plant:

Characteristics of the central plant system for the purposes of simulation are summarized in Table III. As reflected in Table III, the modeling of the central plant was, in all instances, the same. This element of the computerized modeling effort is weak in that it does not account for a number of central plant variables that could significantly affect energy consumption. For example, the computer program does not differentiate between two hermetic centrifugal machines in series or in parallel nor does it project their relative energy consumptions.

TABLE II
MIXING BOX SIZES OF
TDC ADMINISTRATION BUILDING

No. of Boxes	Identity per Schedule	Size cfm
22	"A"	120 to 300
28	"B"	310 to 400
18	"C"	425 to 550
21	"D"	551 to 700
16	"E"	701 to 900
	Volumetric subtotals	41,757 to 56,800

TABLE III
CHARACTERISTICS OF THE CENTRAL PLANT AS MODELED

	Revised Cases	As Built Case
Minimum part load chiller performance	10%	10%
Chilled water pump load	86.0 ft	86.0 ft
Condensed water pump load	60.0 ft	60.0 ft
Boiler-water pump load	30.0 ft	30.0 ft
Fan and pump motor efficiencies	85%	85%
Chilled water leaving temperature	45°F	45°F
No. and size of the chillers	2 @ 78 tons	2 @ 78 tons
No. and size of boilers	1 @ 1440.0 MBtu	1 @ 1440.0 MBtu

The partial load performance of a centrifugal machine, such as the two installed in the TDC administration building central plant is shown in Figure 6. As can be seen, reduction in capacity and power consumption are approximately linear (i.e., in a 1 to 1 ratio) over a range of roughly 50 to 100 percent of rated capacity. Thus, in many instances when two or more chiller packages are installed in parallel and each is operating at less than 50 percent of capacity, the cost of tonnage output from the two or more machines, in terms of electrical input, is considerably more than it would be if only one machine were operating between 50 and 100 percent of capacity and the other machines were idle.

Because of the high pressure drop through the four-pass evaporator section of each machine and the resulting high tube-side water velocity (approximately 10 ft/sec), it would not be satisfactory to "re-pipe" these two machines in series. Improved chiller efficiency by this alternative is not feasible. Severe tube-side errosion problems are generally encountered if the water velocity exceeds 10 ft/sec. Additionally, the design evaporator water side pressure drop (32 ft) prohibits series operation of the chillers. Alternative method -- installation of motor valves and improved staging of the secondary machine as they are presently installed in a parallel configuration. (See Figure 7). It should be noted that the chiller system currently used in the administration building was an efficient choice at the time of installation because of the four-chiller-water-pass

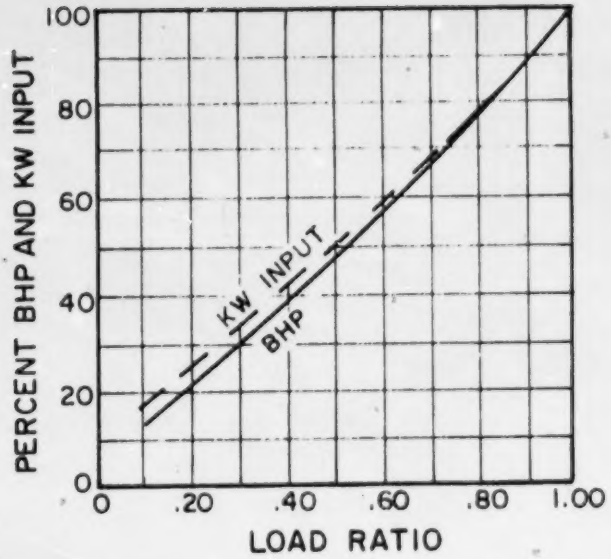

FIGURE 6. TYPICAL PART LOAD PERFORMANCE FOR A HERMETIC CENTRIFUGAL MACHINE.

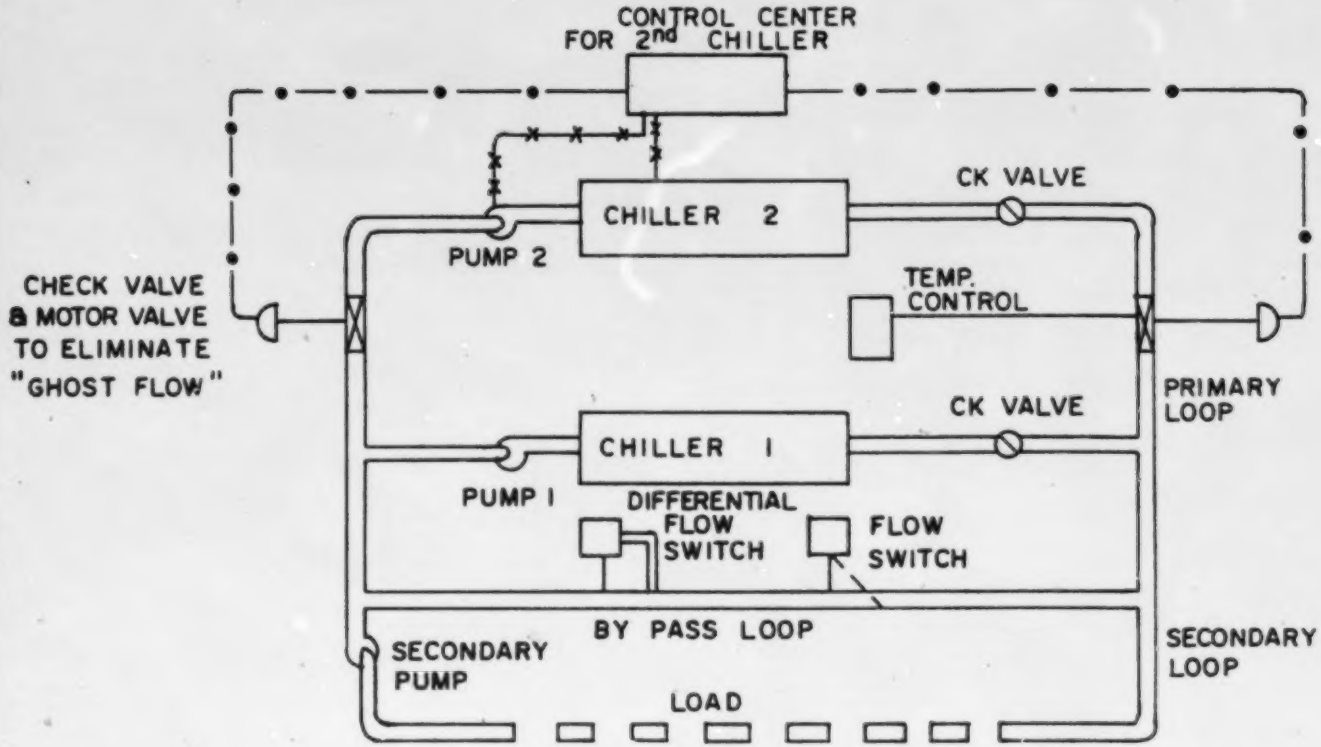

FIGURE 7. CHILLER WATER FLOW LOOP

arrangement through the condensor. These machines consume on the order of 0.88 kwh per ton of cooling. Comparable machines, presently being manufactured, consume approximately 0.71 kwh per ton of cooling primarily because of more efficient motor designs.

As mentioned earlier, the three-pass condensor section selection incorporates a tube-side fouling factor of 0.0005. Design cooling tower water flow through the condensor is 210 gpm, 86°F entering, 96.7°F exiting, and a head loss of 25 ft. There is currently a device on the market that can be installed in-line, that is used to reduce the condensor water tube-side fouling factor.* This device, manufactured by Water Services of America, Inc. (4400 East Broadway; Tucson, Arizona, 85711; ATTN: Wm. D. Robertson; (602) 881-8470 consists of an arrangement of brushes, one for each tube, brush cages, and valves. The brushes are regularly forced by condensor water flow from their cages through the tubes, generally on a daily basis. The flow is then reversed, and the brushes are returned by the reverse flow, to their individual cages in the exchanger heads. The movement of the brushes results in the mechanical removal of residue from the tube walls. This in turn results in the maintenance of an extremely high condensor heat transfer efficiency, and reduces electrical energy consumption of the chiller package. Typically, the fouling factors expected during operation with this type cleaning system are 0.0001 to 0.0002.

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*Implementation of a continuous treatment program would partially eliminate this problem and would also reduce cooling tower "blow down".

Operational cost savings depend upon water treatment and existing maintenance. Typically, installation of this type equipment reduces compressor power consumption from 5 to 20 percent as reported by others with the additional benefit that machine capacity is maintained at 6 to 15 percent above manufactured rated capacity, which is based on a 0.0005 fouling factor consideration. Table IV gives the capacity of each chiller and horsepower requirements as a function of the leaving chilled water temperature and the condensor water supply temperature; these data reflect a condensor water tube-side fouling factor allowance of 0.0005. Some consideration should also be given to waste heat recovery as illustrated in Figure 8.

Cost Factors and Life Cycle Cost Benefits:

The evaluation of alternate forms of potential energy savings can only be done through some form of cost analysis. Examination of the results of Table I, indicate that in some instances it is possible to reduce electrical power consumption by increasing gas consumption and vice versa. Of ultimate interest to the TDC Administration, however, is the maximum cost benefits of reducing energy consumption. NASA's Life Cycle Cost Analysis Program was used, in conjunction with the computer results of Table I, to evaluate life cycle cost. Table V reflects some of the pertinent input data.

The results of this analysis are annuities for each equipment category and for the total HVAC system. These annuities are calculated utilizing present worth techniques;

TABLE IV
CHILLER PERFORMANCE DATA

Leaving Chilled Water Temperature	Entering Condensor Water Temperature 85°F	90°F	95°F	100°F
42°	77.5 tons (92.5 Hp)	72.0 tons (85.8 Hp)	71.8 tons (85.7 Hp)	67.5 tons (80.4 Hp)
45°	85.9 tons (102.5 Hp)	78.9 tons (94.1 Hp)	77.5 tons (92.4 Hp)	76.0 tons (90.6 Hp)
48°	88.5 tons (105.6 Hp)	82.8 tons (98.8 Hp)	82.9 tons (98.9 Hp)	78.2 tons (93.3 Hp)

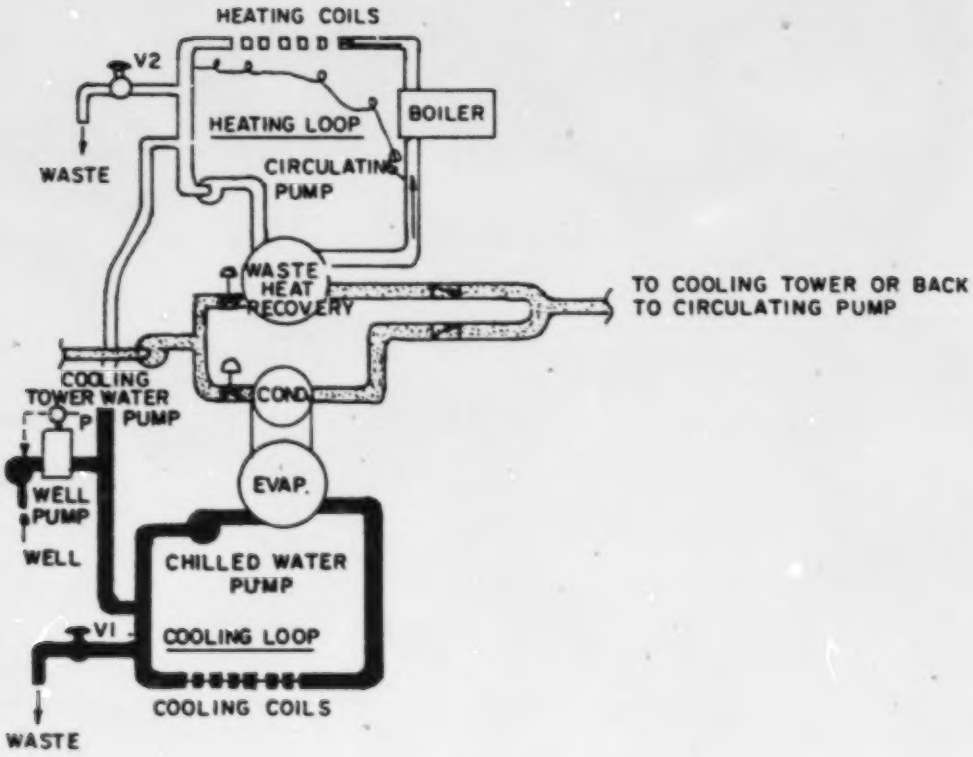

FIGURE 8. CONDENSER WASTE HEAT RECOVERY SYSTEM

TABLE V
LIFE CYCLE COST ANALYSIS INPUT ASSUMPTIONS

I.	Information Supplied by TDC	
	A. Remaining building life	30 years
	B. Annual interest rate	7.5 percent
	C. Estimated labor wage annual increase	8.0 percent
	D. Estimated floor space cost annual increase	7.5 percent
	E. Estimated energy cost annual increase	10.5 percent
	F. Utility cost	
	1. Electrical rate	dollars per kwh
	a. Consumption	0.02
	b. Demand	0.0
	2. Natural gas	dollars per Therm
	a. Consumption	0.32
	b. Demand	0.0
	3. Water	dollars per 1000 gal
	a. Consumption	0.95
	b. Demand	0.0
II.	Information Assumed	
	A. Initial cost of the equipment*	$81,900.0
	B. Anticipated life of equipment	20.0 years
	C. Resale value considered	0.0
	D. Estimated annual maintenance labor cost	$ 1,000.0
	E. Estimated major overhaul labor cost	$ 5,000.0
	F. Estimated major overhaul material cost	$ 4,000.0
	G. Estimated cost of floor space occupied by equipment	$ 100.0

*Based on $525/ton of AC capacity only; 2 x $525/ton x 78 tons = $81,900.0.

they reflect consideration as related only to the HVAC and can be constured to mean the uniform annual cost to an owner during the economic life of the building system. Table VI presents these findings.

As indicated previously, the owning and operating cost data and resulting annuities presented suffer from the weakness associated with unpredictable utility cost increases that can be expected to continue in the near future. Price increases in natural gas are reported to be escalating at 3 percent per month in Houston at present. Additionally, an installed cost of $525 per ton of air conditioning, as was used in the life cycle cost reflects the approximate price of the air conditioning system at the time of building construction in 1965. The data in Table V does not account for any heating equipment cost. Finally, the data presented in Table V is considerably lower than that which would be used by prudent investors in the private sector for a similar building. Accordingly, the annuities generated should be evaluated only as a qualitative long term index.

Significant to any change in equipment in the TDC building is the material and installation cost necessary to install a particular piece of equipment or operation feature. Table VII presents this data. It reflects only the expected direct cost without overlays or contingencies. In all instances, total labor cost was estimated at $27.50 per hour. Material cost estimates and installation labor requirements were provided by manufacturers and represent typical prices expected in the Houston area market.

TABLE VI
LIFE CYCLE COST OF TDC HVAC SYSTEM

I. Existing Double Duct System - Case A

	Annual Cost	Annuity
A. Electrical	$31,682.0	$126,824.0
B. Gas	8,847.0	35,416.0
C. Water	1,010.0	4,044.0
Utility Subtotal	$41,539.0	
D. Equipment		21,405.0
Owning & Operating Annuity		$187,689.0

II. Modified Double Duct System

A. Case B - Hot and Cold Deck Reset; Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,177.0	$72,764.0
2. Gas	510.0	2,042.0
3. Water	326.0	1,305.0
Utility Subtotal	$19,013.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$97,517.0

B. Case C - Hot and Cold Deck Reset; No Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,298.0	$73,249.0
2. Gas	221.0	884.0
3. Water	313.0	1,251.0
Utility Subtotal	$18,832.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$96,789.0

C. Case D - No Hot or Cold Deck Reset Capability; Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,551.0	$ 74,261.0
2. Gas	2,541.0	10,170.0
3. Water	387.0	1,547.0
Utility Subtotal	$21,478.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$107,384.0

D. Case E - No Hot or Cold Deck Reset; No Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,758.0	$ 75,088.0
2. Gas	2,108.0	8,440.0
3. Water	404.0	1,618.0
Utility Subtotal	$21,270.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$106,552.0

III. Variable Volume, Double Duct Heating or Cooling System

E. Case F - Hot and Cold Deck Reset Capability; Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,065.0	$72,315.0
2. Gas	79.0	316.0
3. Water	360.0	1,442.0
Utility Cost	$18,618.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$95,477.0

F. Case G - Hot and Cold Deck Reset Capability; No Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$18,245.0	$73,037.0
2. Gas	76.0	303.0
3. Water	360.0	1,442.0
Utility Subtotal	$18,504.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$96,187.0

G. Case H - Hot and Cold Deck Reset Capability; Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$17,751.0	$71,058.0
2. Gas	66.0	266.0
3. Water	360.0	1,440.0
Utility Cost	$18,177.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$94,169.0

H. Case I - No Hot and Cold Deck Reset Capability; No Economizer Cycle

	Annual Cost	Annuity
1. Electrical	$17,914.0	$71,713.0
2. Gas	64.0	256.0
3. Water	392.0	1,568.0
Utility Cost	$18,370.0	
4. Equipment		21,405.0
Owning & Operating Annuity		$94,942.0

TABLE VII
INSTALLATION COST

Item	Misc. Materials	Unit Prices	Total
A. Convert building from single set Point thermostats to dual set Point thermostats			
1. Materials	$300 + $43/ea x 78	T-stats =	$3,354.0
2. Labor	$200 + $15/ea		1,170.0
	Total This Item		$5,024.0
B. Convert to hot and cold deck reset Capability			
1. Material	$200.0 + $600/deck x 4	deck =	$2,600.0
2. Labor	$100.0 + $220/deck x 4	deck =	980.0
	Total This Item		$3,580.0
C. Install enthalpy economizer cycle			
1. Material			
a. Instrumentation	$100.0	+ $500 =	$ 600
b. Sheet metal duct work & damper			700
c. Additional fans			800
2. Labor			
a. Instrumentation	$100.0	+ $200 =	300
b. Sheet metal duct work			800
c. Additional fan			400
	Total This Item		$3,600

D. Change out all mixing boxes to double duct variable volume boxes (w/re-use of existing damper motors)

1. Material		
a. New boxes		14,500.0
b. Misc. sheet metal work		100.0
2. Labor		3,000.0
		$17,600.0

E. Install variable volume fan control system

1. Materials		
a. Flow metering stations and		3,600.0
b. Inlet dampers for air handlers and outside air		500.0
2. Labor		
a. Flow metering stations		600.0
b. Inlet dampers		200.0
	Total This Item	$4,900.0

F. Install condensor water tube-side cleaning system

1. Material	$400	$2,755/ea	5,900.0
2. Labor			1,000.0
		Subtotal This Item	$6,900.0

G. Misc. to include window film, roof, paint, etc. 1,000.0

The data presented in Table VII should be taken as scope estimates only. Accurate installed labor or material costs can only be determined after detailed plans and specifications have been prepared, and such costs are always subject to current market considerations.

To implement a particular system conversion, it would be necessary to consider one or more combinations of installed cost options. Additionally, some options are meaningless with particular systems. As an example, modification of the existing double duct system together with possible changes to the central plant system could encompass costs associated with: (1) conversion of single set-point to dual set-point thermostats; (2) installation of a hot and cold deck reset capability; (3) installation of an economizer cycle; (4) installation of motor valves and controllers for each chiller; (5) and installation of condensor water tube-side cleaning system. Changing out the mixing boxes and installation of a variable volume fan control system are not relevant and should not be associated with modification of the dual duct system. These two changes would, however, be mandatory for implementation of the variable volume double system. Hence, when the additional instrumentation necessary to provide control linkage -etween potential modifications (estimated not to exceed $2,000 total installed cost) is considered, then maximum installed cost for modifying the existing double duct system or for effecting changes in the system necessary to produce a double duct, variable volume system would be on the order of $20,000 and $42,600, respectively.

Conclusions:

Before a decision can be made to implement a particular energy savings alternate plan, factors, such as the remaining life of energy contracts, future energy resources and costs associated with those resources, and projected administrative space requirements, together with the information developed in this report, must be considered. The prerequisite consideration to any changes should be occupant comfort and tolerance of the operation of the space conditioning system.

The results of this study should be interpreted on a relative basis. The decision to implement a particular change to the space control system should consider, among the aforementioned factors, the frequency and magnitudes of the "loads not met" by a particular system; life cycle costs; direct energy cost; type and magnitude of energy saving, especially if at the expense of another form of energy; and, finally, the cost of implementing the changes that are arrived at after detailed engineering and design results are established.

Finally, if the present air distribution system is modified, it is suggested that the system amperages, voltages, flows, temperature and other data be recorded and periodically checked at intervals of six months to one year. This is the only way that continued high operating efficiency can be maintained.

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